AN INVESTIGATION OF THE TROPICAL HISTOSOLS IN HAWAII

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN SOIL SCIENCE

MAY 1971

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ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the help of the Department of Agronomy and Soil Science and its staff during the course of this study. A Research Assistantship from the Department made the completion of this work possible. Acknowledgement is also due to Mr. R. T. Katekaru, Dr. L. D. Swindale and the Thai Government for making possible the extension of the author's stay at the University of Hawaii.

Thanks are also due to Mr. K. Kartawinata of the Botany Department for his help in the identification of plants from the study sites, to Mr. H. H. Sato, Soil Scientist with the SCS, USDA, for supplying much useful information, to Mrs. T. Ikawa and to Mr. E. T. Fukunaga for their help during field trip on the island of Hawaii.

Some of the photographs given to the author for her use in this dissertation were supplied by Dr. C. L. Schroth, formerly an Assistant Soil Scientist in the Department.

Sincere thanks are expressed to the friends in Hawaii Institute of Geophysics Soil Group for their moral support and the many ways in which they offered assistance.

ABSTRACT

An investigation of Tropical Histosols in Hawaii was made with the objective of examining some of the factors responsible for their formations, determining their nature and properties, testing the parameters recommended for their classification, and examining their histic epipedons.

Hawaiian Histosols are either Tropofolists or Troposaprists. Tropofolists, previously called lithosols, are found on some mountain slopes on the island of Hawaii. One Troposaprist series, the Alakai, previously known as a bog soil, exists in Hawaii and is found on tops of some high mountains under high rainfall. On Oahu, this soil is formed under lower rainfall than encountered on other Hawaiian islands. In all cases, however, the formation of this soil is contributed by fog drips, poor drainage and other factors which assure a high degree of saturation.

Samples belonging to both Great Groups were collected and subjected to detail characterization. Routine measurements were used in which physical and chemical properties were investigated, with more emphasis on the latter.

Tropofolists were found to exhibit moisture characteristics similar to those of the organic layers of Troposaprists. Moisture retention curves of both were "sand type", i.e., large quantity of water were drained at low tensions, yet large amounts of water were retained at 15 bars. Organic matter contents, determined by loss on ignition, ranged from 10 to 90 per cent for the Tropofolists but were

near 90 per cent for the organic layer of Troposaprists. Fiber content determinations in the laboratory were not possible in most Tropofolists but were possible in the Troposaprist. Bulk density determination were possible in only few Tropofolists and in the Troposaprists.

Absorbance of sodium pyrophosphate extracts gave good indication of degree of decomposition only when their values were adjusted according to organic matter contents. For Tropofolists, no correlation was noted between physical properties and degree of decomposition. However, correlations were found between organic carbon and humic acid contents and absorbance of pyrophosphate extracts for which r values were 0.418** and 0.552**, respectively. As expected, oxidizable organic carbon and CEC showed correlations with organic matter contents for which r values were 0.934** and 0.680**, respectively. Total nitrogen was also found to correlate well with organic carbon (r=0.618**). All these correlations exhibited scattered points possibly due to the shallowness of the Tropofolists. Shallowness may have caused errors in soil collection due to varying degrees of rock contamination.

For the Troposaprists, similar statistical interpretation of results were not made due to limited sample size. However, obvious trends were noted between the degree of decomposition and fiber content, humic acid content, and C/N ratio. The degree of decomposition itself increased significantly going down the profile.

Histic epipedons of Hawaiian Histosols were found to be either one of two types. The first showed the characteristics of Tropofolists, and the second showed those of the Troposaprists. As far as classification within the Tropofolists is concerned, it appears that the designations of "euic" and "dysic" do not serve satisfactorily. These terms are arbitrary since they are based on pH measurements which themselves are subjected to great variations, even within one soil series.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Soils can be divided on the basis of organic matter content into two general groups--mineral or organic soils. Mineral soils are those which contain amounts of organic matter varying from a mere trace to as high as 15 or even 20 per cent. On the other hand, soils with organic matter contents ranging from 15 to 20 per cent to as high as 90 or 95 per cent are arbitrarily called organic soils (Buckman and Brady, 1969; The Terminology Committee of Soil Sci. Soc. Am. Proc. 1965). The depth of organic layer is another important criterion used to distinguish soils with humus layers from organic soils. According to the U. S. Soil Classification System (Soil Survey Staff, 1960 and 1968) organic soils, or the soils of the Order Histosol, must have organic layers with thicknesses more than twice as much as those of their mineral horizons.

Organic soils occur throughout the world but they occur most intensively in the cool and moist regions of the northern hemisphere (Farnharm and Finney, 1965). According to Olenin (1963), 60 per cent of the world's organic deposits, which include lignite and coal, are located in Russia. Substantial areas are also found in Finland, Canada, and the United States. Such organic soils, particularly peats, also occur extensively in many areas of the humid tropics. Hock (1968) reported that Indonesia alone has 40 million acres of peat. Olenin (1963) ranked that country the ninth in the world as regards the extent of peat resources. In Malaysia and Sarawak, there are 2 and 3.6 million acres, respectively (Hock, 1968).

Hawaiian organic soils presently appear to have limited potential use as compared to mineral soils. However, their potential may increase because of urban expansion into good agricultural land. The demand for more food and fiber production continues to increase with increased population while good agricultural lands are continually decreased around cities and industrial centers. Organic soils could produce good crop yields when well managed. This is supported by some experiences in other areas of the world. However, such experiences are relatively rare probably due to two factors. First, organic soils require management practices which are more specialized and costly than mineral soils. Second, only limited information exists on the characterization and classification of these soils. There is, therefore, a need to study organic soils from the standpoint of classification so that the information gained will be of benefit in utilizing these soils especially for agricultural lands.

Properties of Organic Soils

Physical Properties

Organic soils are quite different from mineral soils with respect to physical properties. The water holding capacity of an organic soil is several times higher than that of a mineral soil. In fact, an organic soil is commonly known to retain several times its own weight of water. Cline et al. (1955) considered the Alakai peat of Hawaii found at high elevation to be extremely valuable as a reservoir for storing water to irrigate drier land at lower elevations. The rate of water movement in an organic soil, both vertical and horizontal, depends largely on the degree of compaction. Permeability is inversely related to compaction (Cook, 1962). Bulk density is generally very low. It is dependent upon the moisture content, especially at the time of sampling, and upon the proportion of mineral material present. Dehydration causes shrinking and, therefore, increases bulk density. When an organic soil becomes very dry, excessive shrinkage brings about the formation of wide cracks. Such cracks fail to close up completely when the material is rewetted. Therefore, the drainage status of the soil can change permanently (Cook, 1962). Also in this manner, more surface area of the soil becomes exposed to aerobic conditions giving rise to increased oxidation of organic material. "Subsidence" of an organic soil is a term which refers to the reduction of the depth of the soil which gives rise to lowering of land elevation (Jongedyk, Hickok and Mayer, 1951). Such a phenomenon usually occurs after an organic land has been drained. A survey of literature shows that subsidence is a most serious problem as far as utilization of a deep organic soil is concerned (Jongedyk et al., 1950; Weir, 1950; Dawson, 1956). These authors stated that oxidation was the major cause of subsidence as it was responsible for organic matter decomposition and subsequent rotting out. However, fire, compaction, and wind erosion can also be causes of subsidence. Weir (1950) studied the rate of subsidence in the San Joaquin Delta in California. He found that the annual subsidence increment was 7.5 $\pm$ 1.2 cm (0.25 $\pm$ 0.04 ft) during the period 1948-1955. It is obvious, however, that the extent to which an organic soil subsides is dependent upon its depth.

Chemical Properties

Organic matter is generally known to have a high cation exchange capacity (CEC). An organic soil would be expected to have a similarly high cation exchange capacity as well as a high buffering capacity. The cation exchange capacity (CEC as determined by the ammonium acetate method was found to range from 85 to 170 meq/100 g on an air-dry basis (Cook, 1962). CEC values on an oven-dry basis were reported to be as high as 200-400 meq/100 g. Broadbent and Bradford (1952), using $Ba(OH)_2$ as an extracting agent, found that the CEC of organic matter may be as high as 690 meq/100 g. Naylor and Overstreet (1969) found that Ca^{++} in calcium-saturated organic soils was difficult to replace with Na^+. The Ca-Na exchange isotherms determined by Vanselow's and Gapon's equations showed very large selectivities for Ca^{++} over Na^+. Burge and Broadbent (1961) found that organic soils can fix ammonia. The amount of ammonia fixed was linearly correlated with the amount of organic carbon. One molecule of ammonia was fixed for every 29 atoms of carbon in the presence of oxygen and one for every 45 atoms of carbon in the absence of oxygen. They also found that such fixation decreased after blocking the hydroxyl groups through treatments with dimethyl sulfate. They concluded that these groups were involved in the fixation reaction. Harris and Warren (1962) also found that organic soils can fix phosphates, a phenomenon which is quite common to many inorganic soils, particularly those which are highly weathered. These authors reported fixation rates of about 2.88 to 28.8 kg/ha after adding 112 kg/ha of phosphorus. Lucas and Davies (1961) stated that hydrogen-saturated organic soils had a pH value of about 3.0. These conditions often indicated the presence of sulfides and sulfates of aluminum and iron. Values of pH higher than 7.8 indicated the presence of absorbed sodium, while values ranging from 7.2 to 7.8 suggested predominance of calcium in the soils.

Kinds of Organic Soil Materials

Auer (1933) and Dachnowski-Stokes (1933), (cited by Dawson, 1956), considered that organic deposits are the results of accumulation from plant remains and, therefore, may not be defined as soils. However, many authors (also cited by Dawson, 1956) consider such deposits to be soil materials. Dawson (1956) published an extensive review on the different kinds of organic soil materials. These materials may be classified into five different classes.

1. Peat is usually defined as any partially decomposed plant material accumulated in water or in water-saturated soils where deposition from growing plants exceeds decomposition in accumulated deposits.

2. Muck is an organic soil material which has undergone such a high degree of decomposition that identification of the original plant is not possible.

3. Gyttja, a Swedish folkname, is peat derived from planktons and deposited on the bottom of a body of water by sedimentation. Gyttja has a strong, unpleasant smell caused by incompletely oxidized products of anaerobic splitting of proteins by bacteria and fungi (Kubiena, 1953).

4. Dy, also a Swedish folkname, is composed of insoluble salts

of humic acids, mostly commonly salts of calcium, iron, and aluminum. According to Kubiena (1953), this kind of organic soil material usually occurs at the bottom of the brown waters and consists mostly of an amorphous precipitate of humus gel.

5. Marl is an organic soil material of calcium carbonate precipitated in water by the action of plankton. It usually occurs in a mixture with sedimentary peat derived from plants that precipitate the marl.

Of the five kinds of organic soil materials, peat received the most study. This is evidenced by two International Congresses held in Ireland in 1954, and in Leningrad in 1963. This is probably due to its extensive occurrence. In this review, the term peat or peatland is, heretofore, used interchangeably with the term organic soils.

Formation of Organic Soils

It is generally accepted that anaerobic conditions are necessary for organic soil formation (Farnham and Finney, 1965; Buckman and Brady, 1969; and Waksman, 1942). Bailey (1950) contends that in addition to moisture, low pH is required for organic soil formation in the tropics. However, Vageler (1933) reported that organic soils formed underwater and having high base content can be found in the tropics such as in Africa. According to Cline et al. (1955), very shallow organic soils with high lime contents can be found at low elevations in certain areas of Hawaii. It is commonly known that marshes, bogs, and swamps provide suitable conditions for accumulation of plant remains. According to Buckman and Brady (1969), when the when the environment adjacent to these wet areas is favorable, the growth of many plants such as pondweed, cattails, sedges, reeds, and other grasses, mosses, etc., is encouraged. Numerous generations of plants live, die, and sink down. The water shuts out the air, prohibits rapid oxidation, and thus acts as a partial preservative. The decay that does go on is largely due to the action of fungi, anaerobic bacteria, algae, and certain types of microscopic aquatic animals. These organisms break down organic tissues, liberate gaseous by-products, and help in the syntheses of humus, which is a more or less stable dark fraction remaining after the major portion residues have decomposed. The rate of organic soil formation is known to depend upon the number of plants and certain local geological, chemical, topographical, and microclimatological factors (Dawson, 1956).

Classification of Organic Soils

There are two approaches in classifying the organic deposits. As mentioned previously, one is to classify these deposits as peatlands (Heinselman, 1963), and the other is to classify them as organic soils. According to Farnham and Finney (1965), classification of organic deposits in the temperate zone were based on one or more of the following criteria:

1. Topographical-geographical
2. Surface vegetation
3. Chemical properties
4. Botanical origin
5. Morphological properties
6. Genetic processes

In the United States, under the Great Soil Group Classification System, organic soils are referred to as bog or half bog soils. These soils are usually characterized by excessive moisture and poor drainage. According to the New Comprehensive Soil Classification System (Soil Survey Staff, 1969), organic soils are classified as the Order Histosols. Although much information is available on organic soils from the temperate zone, little is known on tropical Histosols in general and on the Hawaiian Histosols in particular. This investigation was conducted to study some of the Tropical Histosols which are found in Hawaii using, as a guideline, the U. S. Comprehensive Soil Classification System (Soil Survey Staff, 1960, 1968, and 1969). The objectives of the study were:

1. To examine some of the factors of formation of Hawaiian Histosols.

2. To investigate the nature, properties, and potential uses of Hawaiian Histosols.

3. To test the parameters recommended for the classification of Histosols.

4. To examine the definition of the organic horizons (the Histic Epipedons) of Hawaiian Histosols.

REVIEW OF LITERATURE

The classification of the Order Histosols (Soil Survey Staff, 1960, 1968, and 1969) is in an early stage of development, and many of the proposed criteria even now are still being modified. This is due to the limited available information as compared to mineral soils. When the U. S. Comprehensive System of Soil Classification was proposed in 1960, as the 7th Approximation, one of the classification criteria spelled out was the definition of a soil horizon. A soil horizon was defined as "a layer within a soil that is approximately parallel to the soil surface and that is produced by soil forming processes but is unlike adjoining layers." The word "epipedon" was used to refer to the surface layer. The word "horizon" when used after a proper name referred to a subsurface layer. The Histic Epipedon is the diagnostic horizon for the Order Histosols and was defined by the Soil Survey Staff (1960) as follows:

> "A horizon at or near the surface, saturated with water at some season unless artificially drained, and meeting one of the following requirements:
>
> 1. A surface horizon, less than 30 cm. (12 inches) thick, with more than 17.4 percent organic carbon (30 percent or more organic matter) if the mineral portion is half clay; with more than 11.6 percent organic carbon (20 percent or more organic matter) if mineral portion has no clay; or with intermediate proportional content of clay and organic carbon. If the epipedon is less than 20 cm. (8 inches) thick, it is still thick enough to satisfy (2) below if the horizons are mixed to a depth of 20 cm. (8 inches).
>
> 2. A plow layer having more than 8.12 percent organic carbon (14 percent or more organic matter) if there is no clay; more than 16.24 percent organic carbon (28 percent or more organic matter) if the mineral fraction is half clay; or intermediate proportional contents of clay and organic carbon.

> 3. A mineral surface layer less than 40 cm. (16 inches) thick that overlies peat or muck, has a content of organic carbon satisfying (1) above, and has a thickness of 10 to 30 cm. (4 to 12 inches)."

As more information was gained, the Soil Survey Staff (1968) presented further proposals for the classification of the Order Histosols in a supplement to the 7th Approximation especially written on Histosols. It contained a Key to Suborders and Great Groups as well as new definitions for the Histic Epipedon and the information on organic soil materials. The classification at the Suborder level is based on the moisture regime, degree of decomposition of organic material, and per cent organic matter. Thus, it is important to consider whether the soils are saturated with water for a certain period of time or never saturated with water for more than a few days. Soils which are saturated with water are grouped according to their degrees of decomposition as high, intermediate, and low. At present, there are 4 suborders with the characteristics discussed below.

Folists is the suborder which includes what has been previously called "litter" or "O" horizon. However, in the Folists, the horizons rest on lithic contact. Soils in this suborder are distinguished from others by the conditions that they are never saturated with water for more than a few days. Furthermore, they contain more than 35 per cent organic matter. The depth of organic soil materials is less than 1 m. More information will be presented in later discussion of the Hawaiian Histosols.

Fibrists, Hemists, and Saprists are the three remaining suborders. They all remain saturated with water for a long period of time. However, they may be artificially drained. Distinctions between these three suborders are based on the degree of decomposition of the original plant materials. Fibrists are organic soils with the least degree of decomposition. Hemists are soils with an intermediate degree of decomposition. Saprists are those with the highest degree of decomposition. These three suborders include organic soils which were previously called peat, mucky peat and peaty muck, and muck, respectively.

Prevailing temperature and the kind of deposits incorporated in the soils are used as criteria for classification at the Great Group and Subgroup levels.

Criteria Used for Classifying Histosols

In addition to the moisture regime, depth, etc., of the organic horizons, the degree of decomposition is an important criterion in the classification of Histosols. Humification or degree of decomposition of the original plant materials appears to be the key property of organic soils because it profoundly affects the behavior of these soils. Boelter (1969), in agreeing with others, found that the hydrologic characteristics of soil, such as water storage and rate of water movement, depend to a large degree on porosity and pore-size distribution of materials and that these characteristics in turn are determined by the degree of decomposition of organic components.

The kind of chemical and/or biological reactions and the presence of certain chemical compounds were also found to be related to the degree of decomposition. Although the degree of decomposition is known to be very important in organic soils, it is not clearly defined and is, therefore, difficult to quantify (Boelter, 1969). It is important to note that most of the properties discussed below are highly related to degree of decomposition.

Morphological Properties

Color--Aside from the soil color determined by means of the Munsell Color Charts, the color of the paste prepared from the organic soil material in saturated sodium pyrophosphate is used to determine the approximate degree of decomposition.

Fiber Content--Boelter (1969) found that fiber content could be used to estimate the degree of decomposition, fiber content decreases as the decomposition progresses. For peat material, the fiber content is distinguishable in the field and it can be easily measured. The Soil Survey Staff (1968) defined fibers as "fragments or pieces of plant tissue retained on 100-mesh sieve." However, "fragments of wood that are larger than 2 cm in cross section and so undecomposed that they cannot be crushed and shredded with one's fingers are not considered fibers."

Physical Properties

Bulk Density--Boelter (1969) considered bulk density also as a parameter to estimate the degree of decomposition. He found that bulk density and fiber content were closely correlated. Bulk density increased as degree of decomposition increased.

Water Holding Capacity--Boelter (1969) also found that water retention at saturation, 0.05, 0.10 and 15 bar suctions were correlated with both fiber content and bulk density. Water retention of peat materials increases with increasing decomposition. Presumably this is because the more decomposed peat material has smaller pores that are not easily drained. Kuntze (1965) recently confirmed that the water holding capacity of peat was dependent on the degree of decomposition.

Thermogravimetric Method--Schnitzer and Hoffman (1966) used a Stanton Recording Thermobalance to heat organic soil sample under stagnant air in a platinum crucible at a constant rate of 5.4°C/min. Differential thermogravimetric (DTG) curves were obtained by plotting weight change per 2.5-minute interval against temperature. They found that the peak heights of the DTG curves near 280° C were related to the degree of humification, moisture content of air dry samples, and the ash content of oven dry samples.

Chemical Properties

Solubility in Sodium Pyrophosphate Solution--This method was developed by Kaila (1956). It uses an alkaline extractant, sodium pyrophosphate, to extract those organic acids that are the products of decomposition. The principles underlying this method are explained in the Discussion of the Results. The use of this method was also recommended by Farnham and Finney (1965).

Cation Exchange Capacity--The cation exchange capacity of organic soil is primarily due to the occurrence of exchangeable hydrogen in the oxygen containing functional groups, such as carboxyl, phenolic, and alcoholic groups of the humic compounds (Schnitzer and Desjardins, 1965). Isirimah et al. (1970) used the method of Jackson (1956) to determine the exchange capacity of organic soils. He found that CEC of organic matter increased with increasing degree of decomposition. These findings are also in agreement with those of Schnitzer and Hoffman (1966).

Functional Groups--Schnitzer and Desjardins (1965) investigated the carboxyl, phenolic, hydroxyl and methoxyl functional groups and obtained trends which showed that increases in the degree of humification were associated with:

(1) increases in carboxyl (-COOH), methoxyl ($-OCH_3$) and to a lesser extent in the C=O groups,

(2) decreases in alcoholic OH groups, and

(3) few or no changes in the phenolic groups.

They believed that the proportion of the oxygen functional groups increased with humification because the aliphatic OH groups changes to C=O and/or -COOH groups which in turn formed more complex structures. This led to more solubility of the materials in the pyrophosphate solution.

Kosaka (1963) measured the methoxyl ($-OCH_3$) content in Japanese upland soils and found that it decreased with increasing degree of decomposition. He categorized the degree of decomposition into five stages. Although he considered this separation was applicable to decomposition in an acid medium, he thought that with some modification it might also apply for decomposition taking place under an environment different from that of their site of investigation.

C/N Ratio--Coulson et al. (1949) and Townsend and Mackay (1963), as reported by Isirimah et al. (1970), found the C/N ratio to be a useful classification criterion. Isirimah and his colleague recently extracted C and N by means of Na-Dowex A-1 Chelating resin, hot water, and sodium pyrophosphate solution. They found that both C and N which were soluble in hot water decreased with increasing degree of decomposition. The C/N ratio also decreased with increasing degree of decomposition. However, no relation was obtained when chelating resin was used.

Ash Content--The ash content of peats depends primarily on the original plants and the soil minerals. Waksman (1942) considered ash content, botanical composition, pH, and nitrogen contents as the four most important criteria for classification. In general, ash content is an indicator for fertility. As ash content increases, the content of available nutrients usually becomes greater (Farnham and Finney, 1965). In the study of organic soils, most investigators used ash content to estimate the organic matter content in the sample (100% - per cent ash content).

Soil Reaction--"Soil pH has often been used as a criterion in characterization, classification, and in estimating the nutrient status, especially of Ca, in the organic soils" (Farnham and Finney, 1965). According to those authors, Puustjarvi (1957) has reported that the pH determination using 1 N $BaCl_2$ (1:4) gives the best correlation with the base status and exchangeable hydrogen. However, according to some authors, the pH determination in mineral soils was unimportant because of seasonal fluctuation of the pH in the A_o horizon.

According to Farnham and Finney (1965), pH determinations have received little or no consideration in organic soils, and it is still not known whether they are significant seasonal variations in their pH values.

The determination of pH with 0.01 M $CaCl_2$ solution is suggested by the Soil Survey Staff (1968) for classifying the soils at the family level. If the soil pH in 0.01 M $CaCl_2$ solution is more than 5.5, the material is considered to be euic. If less, it is considered to be dysic. These two words "euic" and "dysic" are derived from the Greek words "eu" (meaning good) and "dys" (meaning ill). Thus, they are used to refer to high and low base saturation, respectively.

Humic, Fulvic acids, and Humic/Fulvic ratio--Russell (1966) has defined soil organic matter as "a whole series of products which range from undecayed plant and animal tissues through ephemeral products of decomposition to fairly stable and amorphous brown to black material bearing no trace of anatomical structure of material from which it was derived, and it is the latter material that is normally defined as the soil humus." In addition to the products altered by micro-organisms, soil organic matter also contains the products of microbial synthesis (Broadbent, 1965).

Alkaline extractants, particularly NaOH, have been popular reagents for extraction of soil organic matter since they were originally used by Achard in 1786 (Broadbent, 1965). Using NaOH, organic matter is divided into two convenient groups: Nonhumified substances or humin and humic substances, humic and fulvic acids (Dubach and Mehta, 1963; Kononova, 1965).

Humic acids are mixtures of compounds which are soluble in alkali and precipitated by acid. According to Swain (1963), van Bemmelen could separate humic acids into several fractions by electrodialysis. The humic acids are composed of amino acids and phenolic compounds in a manner as yet unknown. Their molecular weights range from 20,000 to 50,000 (Greenland, 1965). As the pH increases the molecules become more highly charged. Furthermore, their titration curve (Scheffer and Ulrich, 1960) shows that many acidic groups are present, about half of which are negatively charged at pH 5 to 7.

Fulvic acids are soluble in alkali but not precipitated by acids. The principle components are a group of phenolic materials probably similar to humic acids but of lower molecular weight (Kononova, 1965) and a group of polysaccharides. The proportion of carboxyl groups is much less than those associated with humic acids (Greenland, 1965).

Humic and fulvic acids have been used in the attempts to develop more precise criteria for characterizing and classifying both mineral and organic soils. McKeague (1967) recognized that humic acids are much less soluble than fulvic acids in neutral solution. He suggested that humic acids should accumulate with unhumified organic materials at the surface horizons of neutral to acidic mineral soils. Furthermore, the information on the humic and fulvic acids suggested that the latter, associated with most Fe and Al compounds, should be the main fraction in the subsurface B horizon. Therefore, the determination of humic and fulvic acids may be used to separate the A and B horizons, especially in those soils where the A horizon has been eroded away. Ratios of carbon in humic and fulvic acids exceeding 50 per cent are characteristic of the A horizon and lower ratios are characteristic of the B horizon.

The ratio of both carbon in humic acid and fulvic acids (Kosaka, 1963) and the ratio of humic to fulvic acids are considered as criteria in classifying organic soils. Rode (1962) found that the humic/fulvic ratio decreased as the degree of decomposition increased. Doleman and Buol (1968) explained that the humic/fulvic ratio of their samples from the Leptists Suborder, a Suborder proposed by them, was smaller than those of the Saprists because the former had been subject to oxidation after severe drainage conditions. The Saprists, therefore, were in a more advanced stage of decomposition than the Leptists.

Botanical Criteria

According to Farnham and Finney (1965), several American investigators have used botanical origin as a basis for soil classification. The types of botanical origin appear to be the most important criteria in the lower levels of classifications because many properties, such as water holding capacity, differ with different plant remains. Feustal and Byers (1930) reported that *Sphagnum* peat possessed the greatest capacity to absorb water, but this capacity decreased with depth, probably due to the more decomposed moss present at deeper horizons. The saw-grass peats of Florida have fairly high moisture holding capacities though not as high as those of the *Sphagnum* moss. Boelter and Blake (1964) found that the moisture retention values of moss peat, expressed on oven-dry weight basis, are greater than those of herbaceous peat.

Histosols in Hawaii

In terms of the U. S. Comprehensive System of Soil Classification, only two Suborders of Histosols are found in Hawaii, the Folists and the Saprists: Table 1 shows the Great Groups, Subgroups, Families, and Series belonging to these two Suborders. Although the so-called lowland peat and muck may be found in Hawaii (Cline et al., 1955), their occurrence is very small, and thus they are not mapped.

Hawaiian Folists

All of the Folists in Hawaii are classified in the Tropofolists Great Group. Formerly, these soils were classified as Lithosols and mapped as land types (Cline et al., 1955). These soils are found on slopes of mountains just below the timberline to elevations around sea-level. However, they are found only on recent volcanic surfaces. On the island of Hawaii, these soils are estimated to cover about 40 per cent of the total land area.*

The prominent morphological characteristic of Folists in Hawaii is the layer of organic matter accumulated on aa or pahoehoe lavas. Apart from that layer, there is little or no visible profile development. The layer of organic accumulation varies in thickness. The organic material is also found in crevices of rocks or collected in pockets. The material is composed of litters of leaves, twigs, and branches and even trunks in stages of decompositions ranging from fresh to nearly completely humified materials. In some locations, the

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*Personal communication, H. H. Sato, Asst. State Soil Scientist, SCS, USDA, Honolulu, Hawaii.

TABLE 1. THE HISTOSOLS IN HAWAII*

Suborder	Great Group	Subgroup	Family	Series	Elevation (m)	Rainfall (mm)
Folists	Tropofolists	Typic Tropofolists	Euic, isohyperthermic	Kaimu	0-303	1,000-1,500
				Papai	0-303	2,250-3,750
			Euic, isothermic	Puna	303-1,061	1,500-2,250
			Euic, isomesic	Mawae	1,061-2,121	1,250-2,000
			Dysic, isohyperthermic	Malama	0-303	1,500-2,250
			Dysic, isothermic	Kiloa	303-1,061	2,250-3,750
			Dysic, isomesic	Lalaau	1,061-2,121	2,250-3,750
		Lithic Tropofolists	Euic, isohyperthermic shallow	Punaluu	0-303	1,000-1,500
			Euic, isothermic shallow	Kona	303-1,061	1,500-2,250
			Dysic, isohyperthermic shallow	Keaukaha	0-303	2,250-3,750
				Ophehikao	0-303	1,000-1,500
			Dysic, isothermic	Keei	303-1,061	2,250-3,750
			Dysic, isomesic	Kahaluu	1,061-1,757	2,250-3,750
				Kekake	1,061-1,757	1,250-2,000
Saprists	Troposaprists	Terric Troposaprists	Clayey, kaolinitic, dysic, isomesic	Alakai	1,061-1,575	2,500-12,500

*From an unpublished report (October, 1969) by SCS, USDA.

organic material may be saturated with water during rainy months (Powers et al., 1932) but not during the entire year. Consequently, most of them rarely remain saturated for a long time.

Obviously the formation of Folists is primarily controlled by the rate of plant invasion. It was found that lichens established themselves first on lava surfaces. Figure 1 shows the lichens on a 1955 lava flow. Higher plants appear later. In Hawaii, Metrosideros polymorpha, ohia lehua, is the most common tree. Forbes (1912), Robyns and Lamb (1939) and Skottsberg (1941) studied plant establishment on drier aa and pahoehoe flows and found that lichens were established more rapidly on aa surfaces, but that higher plants were established first on pahoehoe, particularly in crevices. Atkinson (1969) reported that many investigators observed Metrosideros polymorpha to be the dominant species in the early stages of aa lava flow successions in wet regions. This species tends to increase in number and to form a cover during the first 100 years of succession. However, there was some evidence of partial replacement by other species during the second hundred years of succession. Pandanus tectorius appears near the coast, while Diospyros ferrea and Psychotria hawaiiensis are found inland below 303 m elevation. In addition, at higher altitudes, Cibotium or tree fern increases in number with time. Atkinson also reported that, from the point of view of plant composition, there appears to be little difference between successions on aa and pahoehoe flows in the windward side of the island of Hawaii, the wet region of his study. The number of Metrosideros is often lower on pahoehoe than on aa flows. Skottsberg (1941) noticed that the

Figure 1. Lichens and Ferns on a Recent Lava Flow (1955),
Kapoho, Island of Hawaii

establishment of Metrosideros appears to be at least partly controlled by the number of fissures and cracks. A flow with few fissures tends to have lower density of Metrosideros than a flow with more fissures.

Large species such as Metrosideros and Cibotium provide more shade to other species such as mosses and grasses, and act as protective covers for organic materials present on the forest floor. At high elevations, with adequate rainfall, low temperature, and high humidity, the rate of deposition is higher than the rate of decomposition. Subsequent accumulation of organic material occurs and may result in the formation of Folists in Hawaii.

Hawaiian Saprists

Only one series of this Suborder, namely the Alakai series, occurs on the island of Kauai, Maui, Molokai and Oahu. These soils can be found on mountain tops of these islands at elevations ranging from 1,061 to 1,757 m with mean annual rainfalls ranging from 2,500 to 12,500 mm (Cline et al., 1955). Under very high rainfalls, the soils develop on moderate to steep slopes (as much as 15 per cent). Moir et al. (1935) referred to the Saprists as peats and attributed their formation to the slow seepage of rain water giving rise to anaerobic conditions which are maintained throughout most of the year.

The Alakai series is the soil previously classified as the bog soil of Hawaii. It is developed under water-logged conditions and is characterized by high acidity. The organic accumulation is much thicker and the profile exhibits mineral profile development while the Folists does not.

According to Cline et al. (1955), the profile of the Alakai series is extremely variable from place to place. The profile generally has 10 to 17.5 cm of undecomposed organic remains at the surface. These remains are composed of moss, sedges, and some herbaceous plants. These materials are matted with roots, a large portion of which are living roots. The underlying layer is composed of a raw spongy porous peat that holds extremely high amounts of water. Below this peat layer, there is a more decomposed peat layer mixed with mineral soil material. All horizons or layers in the profile show extremely acid reactions. Underlying the layer of mixed peat and mineral soil is a gray or bluish gray, rubbery, highly plastic, and structureless clay. In most places, there is also a thin layer of yellowish brown, hard ironstone below the gray layer. This ironstone layer, according to Cline et al. (1955), appears to have been formed on the surfaces of rock cores that have been weathered away. He also stated that this layer overlies highly weathered lava bedrock which still shows the original structure and extends to depths of many feet (illustrated by Fig. 5A).

The soils are extremely acid. Therefore, the vegetation must be one that can tolerate a substrate with low content of lime. *Metrosideros* plants growing on these soils are found to be stunted (Cline et al., 1955).

Agricultural Use of Tropofolists in Hawaii

The Tropofolists in Hawaii have some agricultural potential because the organic soil behave as a medium for storing water and nutrient elements. These soils have been used on a limited scale for pasture and crop production and to a certain extent for timber production. However, compared with other soils, they are less productive. Perhaps they can become economically important when there is more pressure for food and fiber production.

Land use recommendations by the Soil Conservation Service in the State of Hawaii are based on crop adaptation to climate and to the nature of organic soil materials.* These recommendations take into account the elevation of the soil site which is divided into three categories, 0 to 303 m, 303 to 1,061 m and 1,061 to 2,121 m. Each of these categories has a recommended use which best suits the soils. Figure 2 shows a pasture on a Tropofolists on the leeward side of the island of Hawaii. The management of these soils is unique because it is difficult to preserve the organic soil material. It is generally noted that once the existing vegetation is removed, the organic material, especially at the surface, easily oxidizes and may disappear within a year's time.

Figures 3 and 4 show the presence of the Tropofolists soil organic material just after the existing vegetation was removed.

Uses of Saprists

The uses of peat which includes saprists, can be divided into four categories: (1) as peat for planting medium, (2) as agricultural land, (3) as watershed area, and (4) as preservation of flora

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*Personal communication, H. H. Sato.

Figure 2. A Pasture in an Area of Tropofolist at 977 m Elevation along Kainaliu Sequence, Kona, Leeward Side of Island of Hawaii

Figure 3. An Area of Exposed Tropofolist after a Forest was Cleared along Stainback Highway, Windward Side of Island of Hawaii. Approximate Elevation is 212 m and Mean Annual Rainfall is 3,500 mm.

Figure 4. A Close-up of a Tropofolist after the Forest was Cleared along Stainback Highway. The Location is the same as Figure 3.

and fauna. The (2) and (3) will be explained below.

Agricultural Uses of Organic Soils--It is generally known that crop yields in organic soils are not as high as in well-drained mineral soils. However, investigators in temperate as well as in tropical regions have used organic soils for truck crops because these soils possess physical properties which are desirable for vegetable production. These soils support pineapple and maize in Indonesia, coffee in British Guiana and Malaysia, and oil palm and rubber in Malaysia (Hock, 1968).

Generally, organic soils such as Saprists are poorly drained. Therefore, the agricultural use of these soils requires installation of artificial drainage systems. According to Hock (1968), Jongedyk et al. (1950), and Weir (1950), the drainage systems must be designed to maintain a high water table. This practice prevents the irreversible drying of the peats, a condition which converts the peats from spongy masses to hard aggregates. The latter cannot absorb water easily and can provide potential materials for forest fires. The maintenance of a high water table also prevents rapid subsidence of the land due to oxidation.

In addition to proper drainage, fertility management is of great importance. The acidic nature of these soils causes some of the essential microelements, such as molybdenum and boron to be unavailable to plants. Most peats are deficient in some macronutrients such as calcium, magnesium, potassium and sodium. The application of lime, therefore, corrects the acidity and furnishes needed calcium to the soils. In Indonesia, according to Hock (1968), the addition of lime, nitrogen, phosphorus and potassium is necessary to obtain increased yields of crops.

DeBano, Mann and Hamilton (1970) found that when organic litter was burned there was a translocation of hydrophobic substances into the mineral soils, thereby producing a water repellent layer. There appear to be no studies on the effect of burning associated with organic soils, although this practice is recommended in Indonesia for production of pineapple and maize in peat soils (Hock, 1968).

Watershed Area--Organic soils which are unsuitable for agricultural uses are recommended for use as watershed areas, perhaps on a limited scale. Van't Woudt and Nelson (1963) reported that the Alakai Swamp on the island of Kauai primarily acts as a collecting and overflow basin. The surface storage capacity of this swamp is probably more than 2,200 acre-feet. The release of water from the surface during dry spells is probably less than 1,100 acre-feet. Boelter (1966) reported that most bogs are not good water storage reservoirs. Undecomposed moss peats have large capacities but provide little storage because large pores release water quickly. Decomposed peats and herbaceous peats have small storage capacities because little water is removed by lowering the water table.

Two profiles of a Troposaprist examined on Mt. Kaala, Oahu, are shown in Figure 5. Figure 5A shows an exposed profile on a road cut with a dark organic layer which is at least two meters thick, while Figure 5B shows an excavated profile in an area of slight depression (Profile II). The dark organic layer in the latter is approximately 80 cm thick and underlain by a mineral horizon composed primarily of anatase and gibbsite.

Figure 5. Hawaiian Troposaprist (Alakai Series) on Mt. Kaala on Island of Oahu. Elevation is 1,220 m and Mean Annual Rainfall is 2,500 mm

A. Exposed Profile on Road-Cut

B. Excavated Profile in an Area of Slight Depression (Profile II)

A

B

DESCRIPTION OF STUDY AREAS

Folists Study Areas

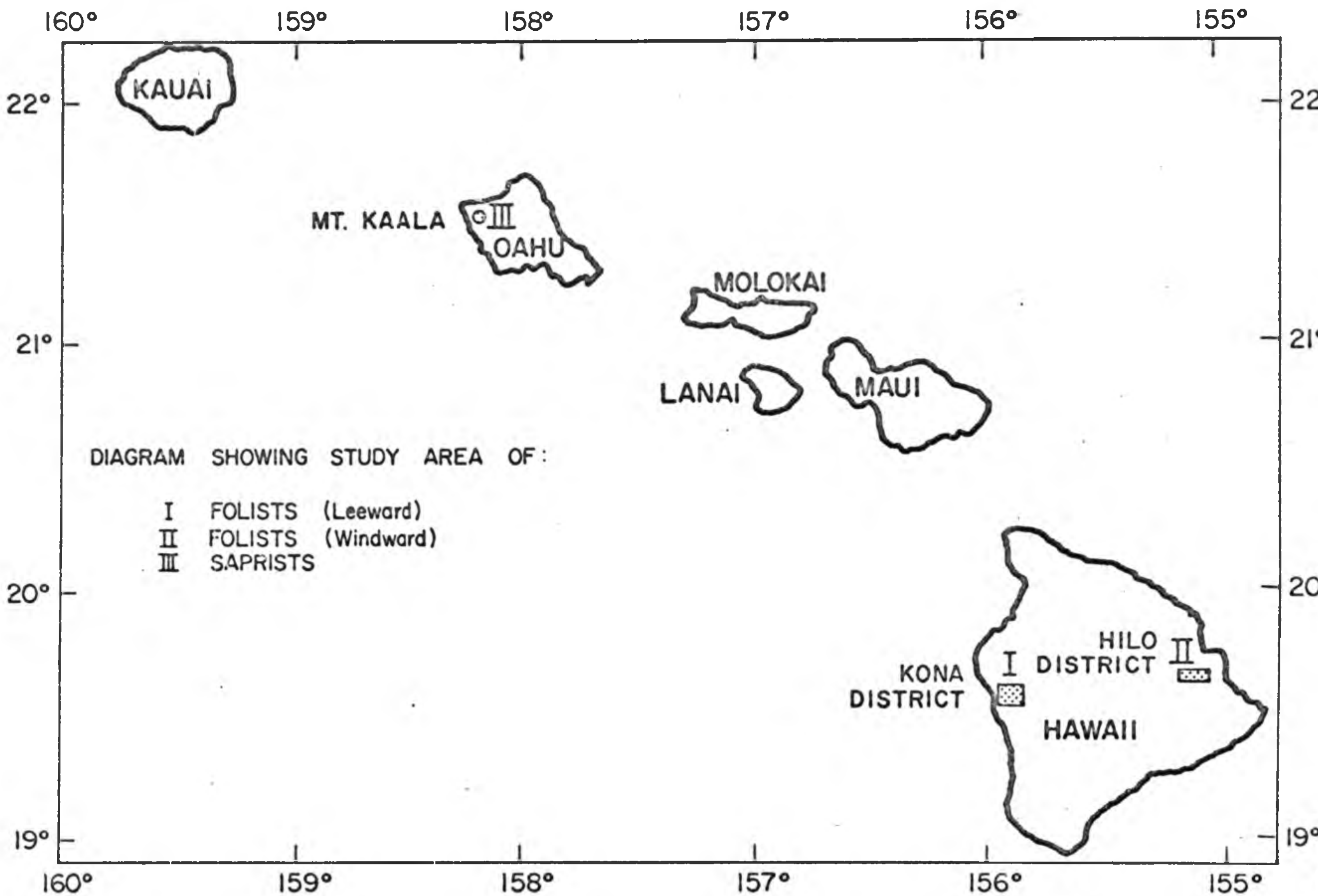
The study areas included both leeward (Kona District) and the windward (Hilo District) sides of the island of Hawaii. The areas lie between northern latitudes 19° 30' and 19° 40' and between longitudes 155° 45' and 156° (Figure 6).

The Leeward Side--Sampling was done in the Kona District, on the western side of the island on the lower southwest slope of the Hualalai, the lower western slope of Mauna Loa, and a westward sloping area between the two volcanoes which is part of an older volcano nearly buried by lafa flows. Elevations within the area ranged from 303 to 1,515 m. Sites were accessible by Jeep trails. The sample sites are described in Appendix II and the location shown in Figure 12.

Climate--The Kona area is located on the western, or leeward, side of the island of Hawaii. Therefore, it is topographically sheltered from the northeast trade winds by Mauna Kea, Hualalai, and Mauna Loa. An outstanding feature of the Kona climate is the system of air circulation (Powers et al., 1932). This air circulation system is featured by a light breeze from the sea to land for a few hours during the middle of the day and a gentle breeze from the land to sea during the night.

The Kona coast of Hawaii has a unique seasonal rainfall regime. The summers are wetter than the winters (Blumenstock and Price, 1967) and November is the driest month. The distributions of rainfall and temperature in relation to elevation are shown in Figure 7. According to Powers et al. (1932), the climate on the mountain slopes of the

Figure 6. Diagram Showing the Location of Study Areas


KAUAI
MT. KAALA
OAHU
MOLOKAI
LANAI
MAUI
HAWAII
KONA DISTRICT
HILO DISTRICT
DIAGRAM SHOWING STUDY AREA OF:
I FOLISTS (Leeward)
II FOLISTS (Windward)
III SAPRISTS
160° 159° 158° 157° 156° 155°
22° 21° 20° 19°

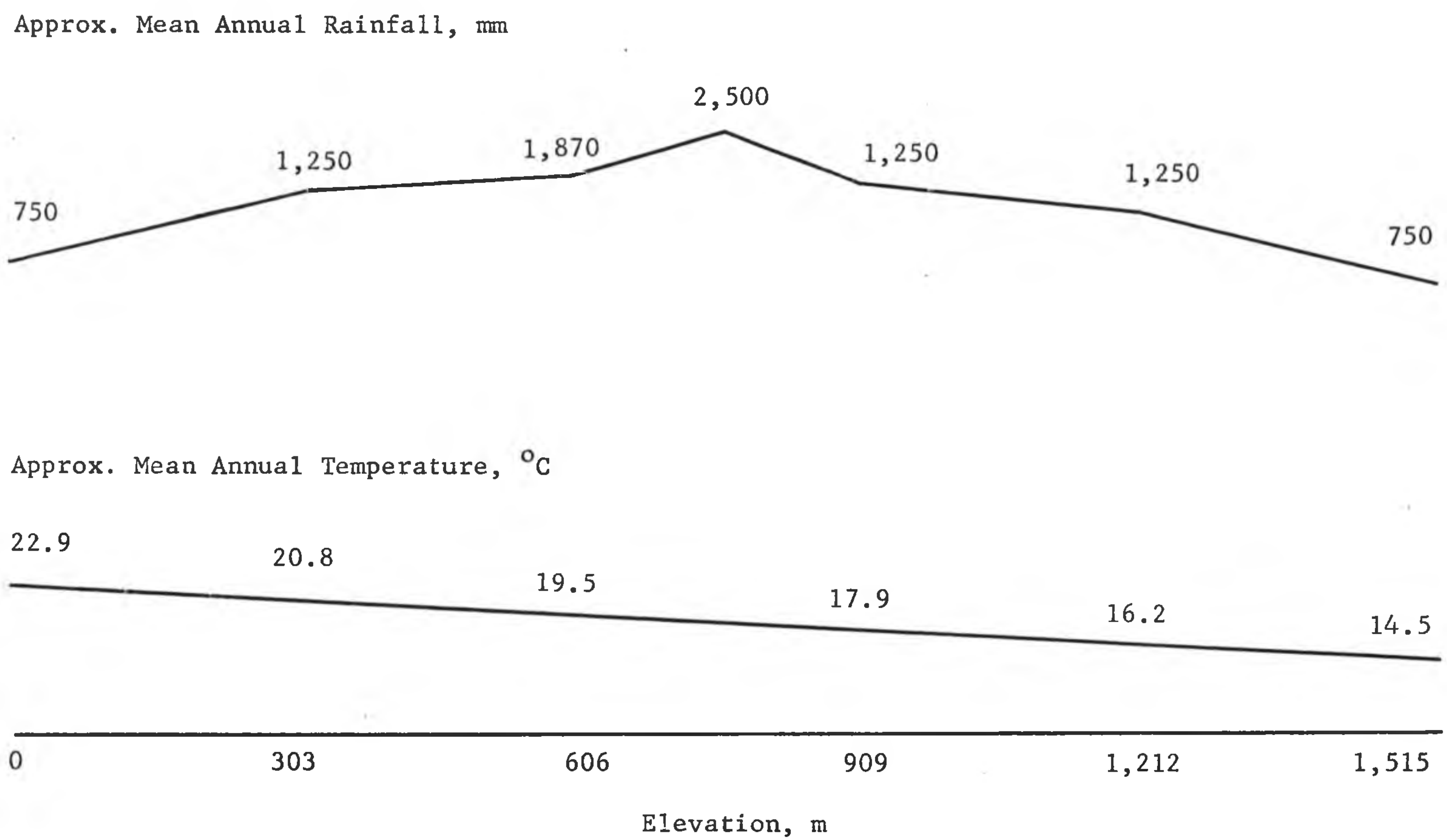


Figure 7. Rainfall, Temperature in Relation to Elevation on the Leeward Side

Kona District at different altitudes may be divided into five different zones: (1) The semi-arid belt, from sea-level to about 242 m, has an annual rainfall ranging from 625 to 1,250 mm and a great deal of sunlight. The vegetation is made up of species that survive under semi-arid conditions. (2) The lower humid belt lies between 242 and 606 m and receives an annual rainfall ranging from 1,250 to 2,500 mm. The sunlight is limited mostly to the morning hours. The soils are moist at all times and are often saturated during the rainy season. (3) The rainbelt includes elevations from 606 to 848 m. This zone is always covered with a cloud blanket even during the dry months and is cloudy almost every afternoon. The mean annual rainfall is more than 2,500 mm and the natural vegetation is dense and is mostly a fern jungle. The soils are always saturated during rainy months. (4) The upper humid belt occurs from 848 to 1,515 m. The rainfall decreases rapidly reaching about 750 mm at the 1,515 m elevation. The soils are fairly moist. During the rainy season, this zone is covered with fog every afternoon. (5) The upper semi-arid belt is located above 1,515 m and will not be described since it was not included in this study.

Geology--The Kona District is covered with more volcanic materials ejected from the relatively young Hualalai volcano than from Mauna Loa. This material is so recent that it determines the geomorphology, soil conditions, drainage, and to some extent, the dominant vegetation.

Topography--The slopes in Kona District are relatively steep. Powers et al. (1932) reported that in some areas the average slope is 292 m/km with some averaging only 132 m/km.

Some lava flows have relatively smooth surfaces, while others have extremely hummocky surface with reliefs of as much as 15 m between depressions and irregular mounds. The local variation in topography together with the differences among the underlying rocks (aa or pahoehoe) have important effects on the drainage conditions in the places with abundant rainfall.

Soils--In the Kona sample site, due to the recent volcanic surfaces, the effect of intense weathering is not yet apparent. The surface layers consist of organic materials with varying thicknesses. The description of the soils in relation to their existing moisture and climatic conditions was mentioned earlier together within the review about climate.

Vegetation--According to Crosby and Hosaka (1955), this area could be broadly classified as an ohia forest type. Figure 8 shows samples of vegetation on this site.

The Windward Side--The area covers the eastern slope of Mauna Loa south of Hilo and covers elevations from 151 to 1,515 m along the Stainback Highway. The sample sites are also described in Appendix II and the location shown in Figures 7 and 13.

Climate--The sample sites on the windward or eastern side of the island of Hawaii is more or less perpendicular to the prevailing flow of the tradewinds. Partly cloudy to cloudy days are common. On the mountain slope, humidity and cloudiness are very high (Blumenstock and Price, 1967). Considerable rain occurs during both the winter and summer months. The mean annual rainfall ranges from 3,125 mm at about sea level and increases rapidly to about 5,500 mm at an elevation of

Figure 8. Vegetation on Leeward Side

606 m. Rainfall starts to decrease to about 3,120 mm at an elevation of 1,515 m (Figure 9) due to the presence of an inversion layer.

The temperature follows a pattern similar to that of the leeward side of the island (Figure 9). Thus, the mean annual temperature is around 22.6°C at sea level and decreases by about 1.67°C (3°F) for every 1,303 m increase in elevation (Blumenstock and Price, 1967).

Geology--Both aa and pahoehoe lavas of the Kau volcanic series occur along the Stainback Highway (Stearns and Macdonald, 1946). According to Wentworth (1938) and Frazer (1960), ash and dust from Mauna Loa and Kilauea eruptions spread over wide areas of Hawaii. Atkinson (1969) reported that field observation of the organic layer overlying these flows did not show any evidence of ash. He concluded that the ash contribution to this area is likely to be small, if any.

Topography--The overall slopes along this study area are long and gentle, averaging 3° to 4° (Atkinson, 1969). Because the surface is recent, the local topography and the underlying rocks may have much influence on drainage and vegetation.

Soil--Similar to the Kona site, due to recent volcanic surfaces, the layers of organic soil material found on the rock varied in their thickness. However, they are generally thicker than the Kona site. Figure 10 shows a sample of Tropofolist profile on this site.

Vegetation--According to the classes described by Crosby and Hosaka (1955), this area is situated within semi-moist and wet areas (1,500 to 2,000 and 2,000 to 3,750 mm of annual rainfall, respectively). Ohia covers the greater part of the forest. Figure 11 shows samples of vegetation on this site. Krajina (1963) considered this area to be

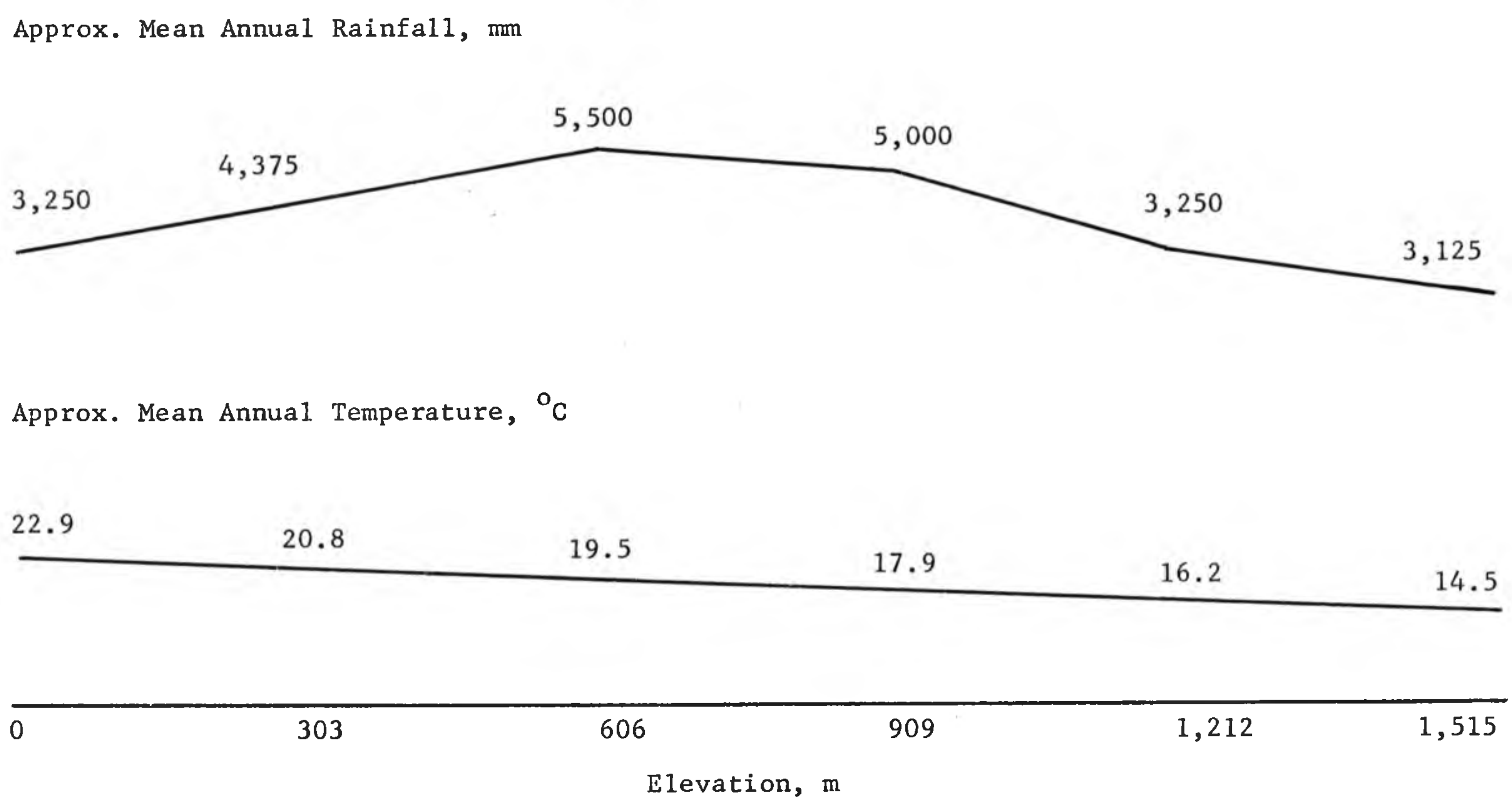


Figure 9. Rainfall, Temperature in Relation to Elevation on the Windward Side

Figure 10. A Tropofolist Profile on Windward Side

Figure 11. Vegetation on Windward Side

in the humid marine tropical or subtropical climate (Zone $D\text{-}0_1$). However, he found that the vegetation was not similar to what he described in his generalized bioclimatic zones, namely, mixed mesophytic tropical and subtropical because Hawaii, being the youngest island in the Hawaiian chain, reflects differences in vegetational and pedological products.

Different structural and compositional rain forest types have been described by Mueller-Dombois (1966). Some of these are found along Stainback Highway from about 610 to 1,524 m elevation. They include open _Metrosideros-Gleichenia_ forest, closed _Metrosideros-Cibotium_ forest, _Cibotium_ forest with scattered _Metrosideros_ and _Acacia koa-Metrosideros-Cibotium_ forest. The latter occurs near 1,524 m elevation.

Further topographic vegetation sequences on the windward side of Hawaii are given by Mueller-Dombois and Krajina (1968).

Saprists Study Area

This study area lies on top of Mt. Kaala, Waianae Range, on the western part of Oahu. It is located between latitudes 21° 30' and 21° 32' 30" and between longitudes 158° 08' and 158° 10'.

Climate--Mt. Kaala is the highest mountain on Oahu. It receives about 2,500 mm of rainfall annually, which though relatively high for Oahu, is considered the lowest when compared to rainfalls in the areas where bog formation occurs in Hawaii. Since the study area is situated on top of the high mountain, the temperature is lower than at the lower elevations approximately 15.4°C.

Geology and Topography--The island of Oahu is composed of two distinct volcanoes, the Waianae and the Koolau ranges. According to Stearns (1966) these volcanoes may have been formed during the Tertiary period. Mt. Kaala is located approximately 15.8 km from the northwest end and about 20 km from the southeast end of the Waianae Range. According to Stearns and Vaksvik (1935), Mt. Kaala is not a peak but a subcircular plateau measuring about 1.6 km across. The plateau is bounded by cliff 303 to 606 m high. A swampy forest covers the plateau.

Soil--A well-developed soil profile with much organic matter is found at this site (Figure 5). The description of the profile is presented in Appendix II.

Vegetation--The vegetation, according to Crosby and Hosaka (1955), is classified as the "bog formation" type. It is wooded Alakai bog (bioclimatic zone D-C_c) in the Hawaiian islands according to the classification developed by Krajina (1963). However, this particular area could not be considered to have an extremely rainy marine sub-tropical climate because the annual rainfall is less than that of the minimum for this climatic zone. Bog formation occurs in this area, nevertheless, due to the fact that it is located in the cloud zone. The dominant plants, according to the above authors are Oreobolus furcatus, Panicum spp., Plantago spp. (lau-kahi-kuahiwi). Larger plants such as Metrosideros and those of Lobelia species which grow as clumps on tops of isolated hummocks are mostly or partially covered with moss. Cheirodendron is another important species among the trees found at this location.

MATERIALS AND METHODS

Method of Sampling

Sample sites were chosen on mountain slopes so that they could be collected from different climatic zones which in turn reflect differences in vegetation. The samples were collected within the forest approximately three and 10 m from the trail or highway. Dry or very shallow samples were taken as "grab" samples. This was especially true for most samples on the leeward side. Most sample sites were located between trees while the rest were located close to tree trunks. Almost all samples on the windward side were dug to the bedrock and clods of the samples were taken from various depths to obtain composite samples. Some samples were relatively dry, some were moist, while others were near saturation at the time of collection.

Sample depths were obtained by inserting a calibrated stick down through the soil until the bedrock was reached. This was repeated several times around the particular sample site. The average represented the depth of the sample.

Preparation of Sample

The samples were stored moist in double plastic bags and kept in a room with constant and relatively low temperature (20°C) to minimize microbial activities. Clods of some samples were used for bulk density determinations. As much as possible, fresh roots, leaves, twigs and rocks were carefully hand-picked and removed. Samples were mixed by hand and prepared for physical and chemical analyses. Small subsamples were air-dried and ground by means of a Pitchford Model

3800 Vibratory Grinder until fine enough to pass through a 100-mesh sieve. These air-dried subsamples were kept in small vials for organic carbon, total nitrogen, pyrophosphate solubility, and loss on ignition determinations. They were also used for Kaila's colorimetric procedure for determining pyrophosphate solubility as described by Schnitzer and Desjardins (1965).

Methods of Analyses

Most of the methods employed in this study are routine measurements which are published in various books and journals. Modifications were kept at a minimum but described adequately within this section, where necessary.

Physical Properties

Water Retention at Saturation and 1/20 Bar--The sample was presoaked for 24 hours or more in a cylinder fitted with a cheesecloth by means of a rubber band over the lower end. Cylinders containing soaked samples were transferred onto a blotter paper on a tension table. The level of water was set so that the tension was zero. After two days, the sample was considered to be at equilibrium, and the weight of the sample was then recorded for calculating water retained at saturation.

To calculate the water retained at 50 cm, the sample was replaced on the tension table, and the water level in the hanging column was lowered by 50 cm from the former position. The sample was allowed to reach equilibrium as determined by a constant weight of the sample after a given time. Finally, the sample was oven-dried and the oven-dry weight of the soil was obtained.

Water Retention at 1/10, 1/3 and 15 Bars--Water retention at each of these tensions was measured by the pressure-plate apparatus (U. S. Salinity Laboratory, 1954). The sample was presoaked with water in a rubber ring which was set on a porcelain pressure plate for overnight or more to ensure saturation. The excess water on the plate was drained before the pressure apparatus was assembled. The pressure was adjusted as desired. After each equilibrium was established, the moisture content of each sample was determined by oven drying at 105°C. It is worthwhile to note that many samples of the Tropofolists which were difficult to wet were soaked in a beaker of water and subjected to a vacuum for several hours to allow the water to soak in more thoroughly.

Bulk Density--The bulk density was determined by the clod method (Blake, 1965). Due to the lightness of the samples, a lead tare weight was used for this determination. The sample and the tare were dipped in molten paraffin, lifted, and allowed to drain. When the paraffin solidified, the weight of the clod, the lead tare, and the paraffin was determined in air and then in water. The densities and volumes of lead and paraffin were taken into consideration when calculating the volume of the sample. Finally, after removing the lead and paraffin, the sample was oven-dried to express the results on an oven-dry basis (Blake, 1965).

Fiber Content--The fiber content is the measure of coarse organic fraction above 100-mesh sieve (Soil Survey Staff, 1968). The sample was presoaked in water overnight. Then, it was transferred onto a 100-mesh sieve, rubbed lightly with the fingers, and washed with water to pass the fine material through the sieve. The organic fraction retained on the sieve was oven-dried and calculated as per cent fiber on an oven-dry basis. However, this method is not applicable for the Tropofolists due to the problems discussed in the section, Results and Discussion.

Color Determination with Saturated Sodium Pyrophosphate--The degree of decomposition was measured by inserting a white filter paper into a paste of organic material in a saturated sodium pyrophosphate solution at $20^{o}C$ ($68^{o}F$). The color of the material absorbed on the filter paper was compared with Munsell Soil Color Charts for an approximate assessment of the degree of decomposition (Soil Survey Staff, 1968).

Chemical Properties

Organic Matter by Ignition--Half a gram of 100-mesh sieved sample was heated at $700^{o}C$ for 3 hours. The weight loss was considered as an estimate of organic matter content.

Organic Carbon--(Modified Walkley-Black Method). A 0.05 g of 100-mesh of sieve soil was mixed with 10 ml of N $K_2Cr_2O_7$. Twenty ml of concentrated sulfuric acid was added and the mixture was allowed to stand for about 30 minutes. The solution was back titrated, after diluting with distilled water, with standard N ferrous sulfate solution using barium diphenylamine as an indicator.

Total Nitrogen--(Kjeldahl Method). The Kjeldahl procedure used for the determination of total nitrogen involved two steps. First, the sample was digested to convert the nitrogen to ammonium. Secondly, the ammonium was determined by distillation, entrapment, and subsequent titration with a standard acid. In this study, 1.00 g of sample was used.

Absorbances of Pyrophosphate Extracts--The method proposed by Kaila (1956) and described by Schnitzer and Desjardins (1965) was used. A 0.5 g sample (oven-dry basis) was shaken with 50 ml of 0.025 M sodium pyrophosphate solution at room temperature for 24 hours. The suspension was filtered and the filtrate diluted to 250 ml with distilled water. The absorbance of the solution was measured at a wavelength of 500 mm by means of a Coleman colorimeter. To obtain cardinal numbers of per cent absorbance, the results were multiplied by 100. Absorbance values were later adjusted according to organic matter content and resulting figures were used to establish a relative scale for degree of decomposition.

Humic and Fulvic Acids--Five grams of sample (oven-dry basis) were shaken in 50 ml of 0.5 N NaOH solution for 12 hours without any acid pretreatment. The mixture was centrifuged and the supernatant liquid was saved. The residue was then washed three times with distilled water, and the washes were added to the extract and made up to 200 ml. Ten ml of this solution were drawn, oven-dried, weighed, and recorded as humic and fulvic acids.

To precipitate humic acid, 10 ml of N HCl solution was added to 50 ml of the extract and left overnight. The supernatant liquid was drawn, oven-dried, and weighed to obtain the fulvic acids. The difference between the two weights was considered as humic acids. In calculation, the contribution of added reagents were taken into account.

Soil Reaction--Soil pH was determined in 1:1 mixtures with water, N KCl solution, and 0.01 M $CaCl_2$ solution using a Beckman Research pH meter.

Cation Exchange Capacity and Exchangeable Bases--The cation exchange capacity was twice determined by the ammonium saturation method, using ammonium acetate solutions at pH 4 and 7. The sample was leached with 1 N ammonium acetate solution to remove the natural exchangeable cations and to saturate the exchange sites with ammonium ions. Excess ammonium acetate was removed with methyl alcohol. The exchangeable ammonium was then determined by distillation, entrapment in boric acid, and subsequent titration with a standard acid. Exchangeable calcium, magnesium and sodium were determined in the ammonium acetate leachate by means of a Perkin-Elmer, Model 303, atomic absorption unit.

RESULTS AND DISCUSSION OF RESULTS

Characteristics of Hawaiian Tropofolists

The data on environmental factors and the morphological characteristics of the Tropofolists are presented in Tables 2 through 4, location of the samples are in soil maps (Figures 12 and 13), and the legend of this map is in Appendix I. Data pertaining to the properties of these soils are presented in Tables 5 through 20 in subsequent pages.

Morphological Characteristics

Color--The soil colors as determined with Munsell Color Charts were mostly very dark brown to black. Although there were some differences, the colors could not be differentiated by means of the charts. Generally, the materials which were highly decomposed were blacker or darker than those which were less decomposed.

The color of the extract obtained with the saturated pyrophosphate solution was below or on the value-chroma line that was prescribed for the Saprists by Soil Survey Staff (1968). This line is drawn to include extracts with colors darker than a value-chroma Munsell notation of 5/1, 6/2, and 7/3. Such a result suggests that although many of the Hawaiian Histosols appear to be only moderately decomposed, they, nevertheless, are highly decomposed according to the pyrophosphate extract solubility test.

Structure--Most samples from the higher rainfall area had weak crumb structure with few exhibiting a massive character. Those from

TABLE 2. GEOGRAPHIC REFERENCE POINTS OF SAMPLE SITES--KEALAKEKUA SEQUENCE

Sample No.	Mapping Unit	Soil Series	Elevation (m)	Approximate Rainfall (mm)	Approximate Temp. °C	Underlying Rock	Ave. Depth (cm)	Color (Pyrophosphate)
5	rLW	(Pahoehoe)	1,303	750-1,250	15.4	pahoehoe	0-5.0	7.5YR 4/4
6	rLW	(Pahoehoe)	1,303	750-1,250	15.4	pahoehoe	0-5.0	10YR 4/3
7	rMWD	Mawae	1,212	750-1,250	16.5	pahoehoe	0-7.5	7.5YR 3/2
8-1 8-2	rMWD	Mawae	1,121	1,000-1,500	17.6	pahoehoe	0-7.5	7.5YR 4/4 7.5YR 4/4
9A-1 9A-2	rKXD	Kiloa	970	1,000-1,500	18.7	aa	0-15	10YR 6/3 10YR 6/3
9P-1 9P-2	rMWD	Mawae	970	1,000-1,500	19.8	pahoehoe	0-15	10YR 5/3 7.5YR 4/4
10-1 10-2	rKXD	Kiloa	727	2,250-2,750	19.8	aa	0-10	10YR 6/3 10YR 6/3
11-1 11-2	rPXE	Puna	591	2,000-2,500	19.8	pahoehoe	0-10	10YR 6/4 10YR 5/4
12-1 12-2	rPXE	Puna	515	1,750-2,750	19.8	aa	0-10	10YR 6/3 10YR 6/3
13-1 13-2	rPYD	Punaluu	333	750-1,250	20.9	pahoehoe	0-5	10YR 6/3 10YR 6/3
14-1 14-2	rLV	(Aa)	303	750-1,250	20.9	aa	0-5	10YR 6/3 10YR 6/3

TABLE 3. GEOGRAPHIC REFERENCE POINTS OF SAMPLE SITES--KAINALIU SEQUENCE

Sample No.	Mapping Unit	Soil Series	Elevation (m)	Approximate Rainfall (mm)	Approximate Temp. °C	Underlying Rock	Ave. Depth (cm)	Color (Pyrophosphate)
16-1	rKHD	Kekaha	1,242	750-1,250	14.8	aa	0-10	7.5YR 4/4
16-2								7.5YR 4/4
15-1	rKHD	Kekaha	977	1,000-1,500	17.0	aa	0-10	7.5YR 4/4
15-2								7.5YR 4/4
17-1	rKHD	Kekaha	909	1,000-1,500	17.0	aa	0-10	10YR 4/4
17-2								10YR 6/3

Figure 12. A Soil Map of the Tropofolists Study Areas on Leeward Side, Kona District, Showing Sample Sites along Two Jeep Trails. General Location is Shown in Figure 6 and Soil Legend is Cited in Tables 2 and 3 and in Appendix I.

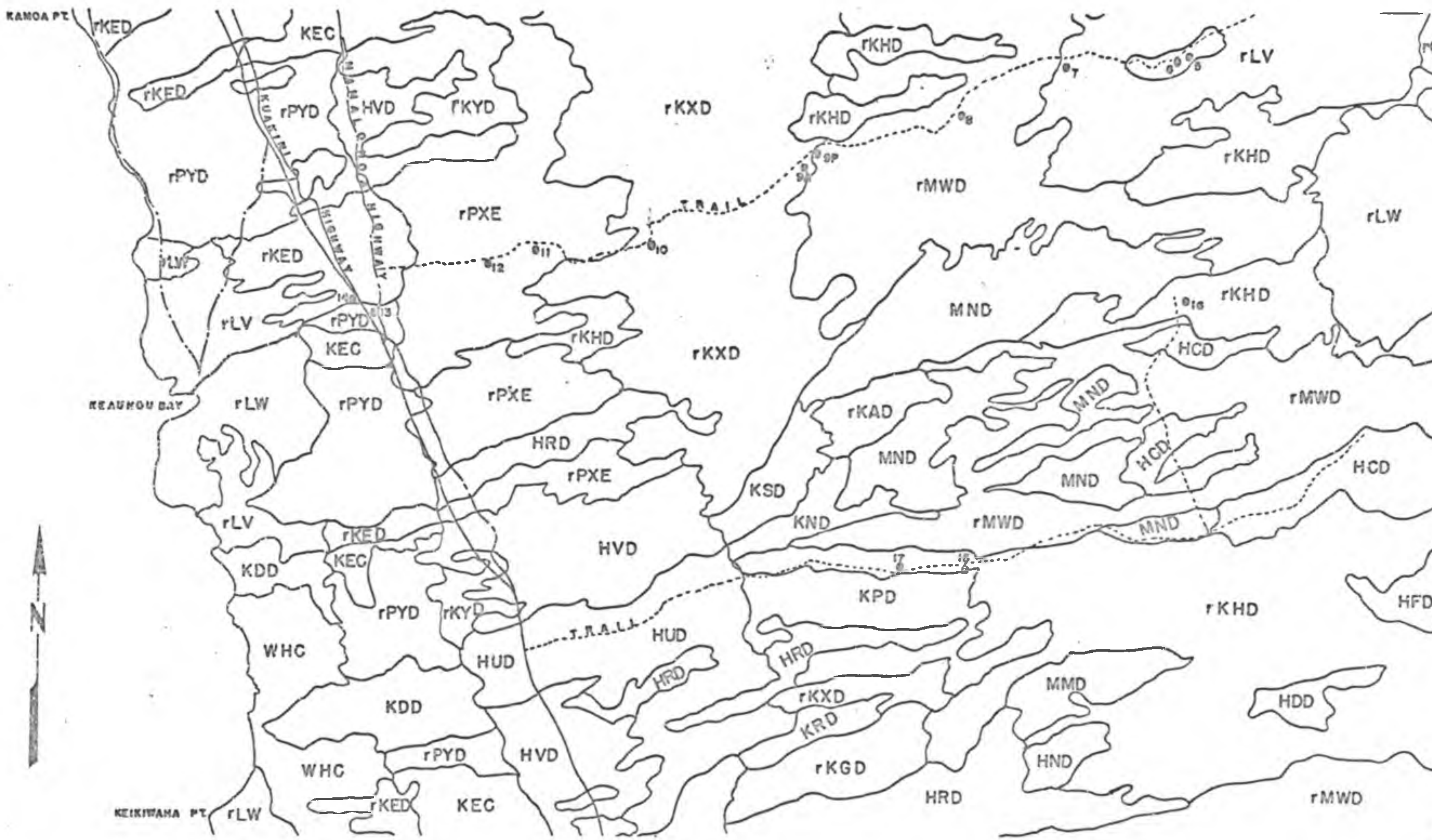
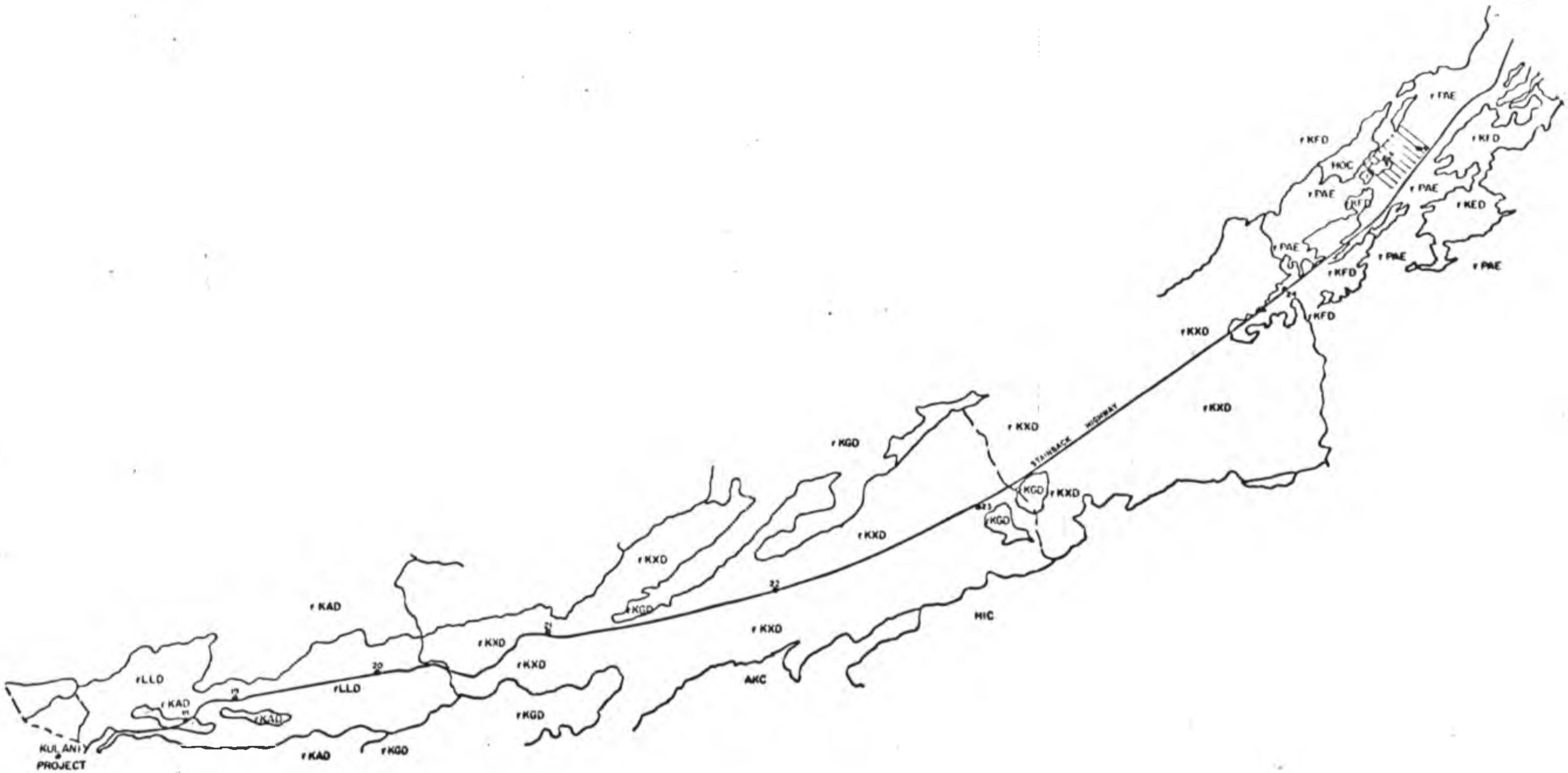

KANOA PT.
KEAUHOU BAY
KEIKIWAHA PT.
KUAKINI HIGHWAY
MAMALAHOA HIGHWAY
TRAIL
TRAIL
N
rKED
KEC
rPYD
HVD
rKYD
rKXD
rKHD
rLV
rCL
rPXE
rMWD
rLW
MND
HCD
rKAD
KSD
KND
KPD
HUD
HRD
rKGD
KRD
MMD
HND
HDD
HFD
KDD
WHC
rLW
rLV
rPYD
rKHD
rPXE
HVD
rKYD
HUD
rMWD
rKHD
HCD

TABLE 4. GEOGRAPHIC REFERENCE POINTS OF SAMPLE SITES--STAINBACK HIGHWAY SEQUENCE

Sample No.	Mapping Unit	Soil Series	Elevation (m)	Approximate Rainfall (mm)	Approximate Temp. °C	Underlying Rock	Ave. Depth (cm)	Color (Pyrophosphate)
18-1 18-2	rKAD	Kahaluu	1,439	3,200	14.3	aa	15	10YR 6/3 10YR 6/3
19-1 19-2	rLLD	Lalaau	1,364	3,200	15.4	aa	25	10YR 6/4 10YR 6/3
20-1 20-2	rLLD	Lalaau	1,212	2,250-2,750	16.5	aa	27	10YR 6/3 10YR 6/3
21-1 21-2	rKXD	Kiloa	1,015	3,750-4,500	17.0	aa	27	10YR 6/3 10YR 6/3
22-1 22-2	rKXD	Kiloa	818	4,750-5,250	18.7	aa	30	10YR 5/4 10YR 6/3
23-1 23-2	rKXD	Kiloa	606	5,250-5,500	18.7	aa	22	10YR 6/3 10YR 6/3
24-1 24-2	rKFD	Keaukaha	303	4,000-4,500	20.9	aa	20	10YR 6/3 10YR 6/3
1	rKFD	Keaukaha	151	3,200-3,250	21.7	aa	7	10YR 6/3
2	rPAE	Papai	151	3,200-3,250	21.7	aa	5	7.5YR 4/4
4	rPAE	Papai	151	3,200-3,250	21.7	aa	5	10YR 5/4

Figure 13. A Soil Map of the Tropofolists Study Area on Windward Side Showing Sample Sites along Stainback Highway. General Location is Shown in Figure 6 and Soil Legend is Cited in Table 4 and in Appendix I.


STAINBACK HIGHWAY
KULANI PROJECT
r LLD
r KAD
r KAD
r LLD
r KAD
r KAD
r KGD
r KXD
r KXD
r KGD
r KXD
r KGD
r KXD
r KGD
r KXD
AKC
HIC
r KXD
r KGD
r KGD
r KXD
r KXD
r KXD
r KFD
r KFD
r PAE
r PAE
r PAE
r KED
r PAE
r PAE
r KFD
HOC
r KFD
r PAE
19
20
21
22
23
24

the drier areas had granular to subangular blocky structure and were mostly loose.

Fiber Content (field)--The fiber content shown in the soil description (Appendix II) refers to amount of fresh to moderately decomposed roots. In some instances, however, especially in the samples that were collected dry, the origin of the fiber is beyond recognition. The determination of the fiber content in the field as well as in laboratory proved to be difficult. Although fiber content is an essential criterion in the U. S. Soil Classification System, it has not previously been used as far as Hawaiian Tropofolists are concerned.

Consistency--Consistencies of the moist Tropofolists were generally slightly sticky and slightly plastic. However, the consistency of the dried soils were nonsticky and nonplastic indicating permanent change in soil physical behavior as a result of drying.

Depth--The depth of the samples varied from less than 2.5 cm to as much as 40 cm. The average depth at each sample site is shown in Tables 2, 3, and 4. It is possible that errors occurred in this measurement since many underlying rocks had undergone disintegration which produced a soft layer, mixed with organic materials which was probably penetrated by the measuring stick. It is also possible that the measuring stick was occasionally inserted into rock crevices. Due to these combined factors the resulting measurements of depth were probably overestimates of the actual depths of the organic layer.

Boundary--The boundaries between the organic soils and the parent rocks were irregular and dependent upon the type of underlying lava.

More irregular boundaries were encountered when aa lava rather than pahoehoe lava comprised the underlying rock.

Physical Properties

Water Retention--Data on water retention at saturation and at 1/20, 1/10, 1/3, and 15 bars are presented in Tables 5, 6, and 7. At saturation, the water content ranged from 136 to 764 per cent, based on an oven-dry sample weight. At 1/20, 1/10, and 1/3 bar, the water content ranged from 85 to 480 per cent, 85 to 475 per cent, and 83 to 364 per cent, respectively.

The moisture release curves of some of the samples are shown in Figures 14 and 15. Each sample was selected on the basis of a representative elevation, rainfall, organic matter, or observed dryness. Samples 8-1, 14-1 and 15-1 were quite dry when sampled, and they were difficult to wet. Samples 8-1 and 18-1 were collected from a high elevation and low rainfall area and contained substantial amounts of organic matter. Sample 9P-1 came from a high elevation area, quite wet, and underlain by pahoehoe lava. Samples 10-1 and 21-2, both contained small amounts of organic matter and were collected from the highest rainfall areas of the Kealakekua and the Stainback Highway sequences. Finally, samples 14-1 and 23-2 were collected from a low elevation and high rainfall areas.

As seen from Figures 15 and 16, soil moisture characteristics showed pore size distributions which are quite variable among samples. Two distinct cases can be observed in this regard. The first case showed some samples, such as 9P-1 (Figure 15), contain

TABLE 5. WATER RETENTION OF HAWAIIAN TROPOFOLISTS--KEALAKEKUA SEQUENCE

		Water Content (g/100 g)			
Sample No.	Saturation	1/20 bar	1/10 bar	1/3 bar	15 bar
5	300.45	135.22	137.04	125.38	102.29
6	308.89	150.29	150.04	141.52	132.77
7	356.04	171.18	171.13	153.82	97.33
8-1	330.51	257.98	184.23	181.06	144.10
8-2	377.96	198.43	166.87	142.67	114.91
9A-1	388.10	209.68	193.26	152.16	127.39
9A-2	310.27	204.42	188.10	159.37	82.32
9P-1	642.10	359.24	332.61	277.23	137.41
9P-2	567.94	320.23	314.71	255.38	132.57
10-1	358.29	251.16	243.72	230.55	142.76
10-2	305.27	187.23	189.26	168.58	118.52
11-1	221.21	132.55	129.33	120.81	93.96
11-2	366.21	252.76	246.59	241.54	157.13
12-1	215.15	136.44	117.65	109.18	66.52
12-2	299.98	237.54	236.69	236.15	170.65
13-1	176.78	106.06	99.33	99.33	72.68
13-2	136.96	84.85	84.60	82.76	63.85
14-1	246.56	144.04	141.33	119.03	96.95
14-2	239.28	164.32	144.36	110.74	95.67

TABLE 6. WATER RETENTION OF HAWAIIAN TROPOFOLISTS--KAINALIU SEQUENCE

	Water Content (g/100 g)				
Sample No.	Saturation	1/20 bar	1/10 bar	1/3 bar	15 bar
16-1	170.10	126.21	106.26	102.14	61.37
16-2	291.19	188.83	158.29	157.89	145.14
15-1	158.51	109.19	101.33	98.65	55.52
15-2	272.84	178.77	160.88	141.81	102.48
17-1	207.63	133.41	120.34	100.86	83.22
17-2	195.29	109.36	105.30	95.29	66.63

TABLE 7. WATER RETENTION AND BULK DENSITY OF HAWAIIAN TROPOFOLISTS--STAINBACK HIGHWAY SEQUENCE

	Water Content (g/100 g)					
Sample No.	Saturation	1/20 bar	1/10 bar	1/3 bar	15 bar	Bulk Density* (g/cc)
18-1	764.19	480.22	475.30	335.05	191.10	0.13
18-2	720.52	467.49	455.07	364.39	263.69	0.13
19-1	367.31	227.43	203.65	192.55	112.58	-
19-2	296.82	187.02	168.70	108.60	65.36	-
20-1	368.64	255.42	238.29	188.66	110.55	-
20-2	465.06	339.63	331.13	223.37	117.98	0.21
21-1	268.37	194.71	188.12	124.14	94.43	-
21-2	288.81	215.42	218.98	176.78	134.88	0.27
22-1	416.83	318.94	318.28	240.82	164.04	0.30
22-2	389.14	268.53	252.35	198.19	128.23	0.25
23-1	219.94	162.62	158.08	149.17	88.74	-
23-2	355.26	236.42	227.17	184.17	142.42	-
24-1	359.15	244.56	237.85	204.55	197.64	-
24-2	267.31	188.60	184.54	175.11	141.40	0.32
1	536.46	282.01	206.89	202.54	130.64	-
2	454.11	258.63	200.00	190.90	133.48	-
4	335.11	181.36	168.99	155.55	115.41	-

*Data is reported for some samples only due to difficulties, reported in the Results and Discussion.

Figure 14. Moisture Release Curves of Some Hawaiian Tropofolists on Leeward Side of Hawaii Island

Sample No.	Elev. (m)	R.F. (cm)	Underlying Rocks	OM Content (%)	Moisture Condition
8-1	1,212	100-150	pahoehoe	81.87	dry
9P-1	970	100-150	pahoehoe	66.68	wet
10-1	727	225-275	aa	67.23	wet
14-1	303	75-125	aa	70.43	dry
15-1	977	100-150	aa	68.20	dry

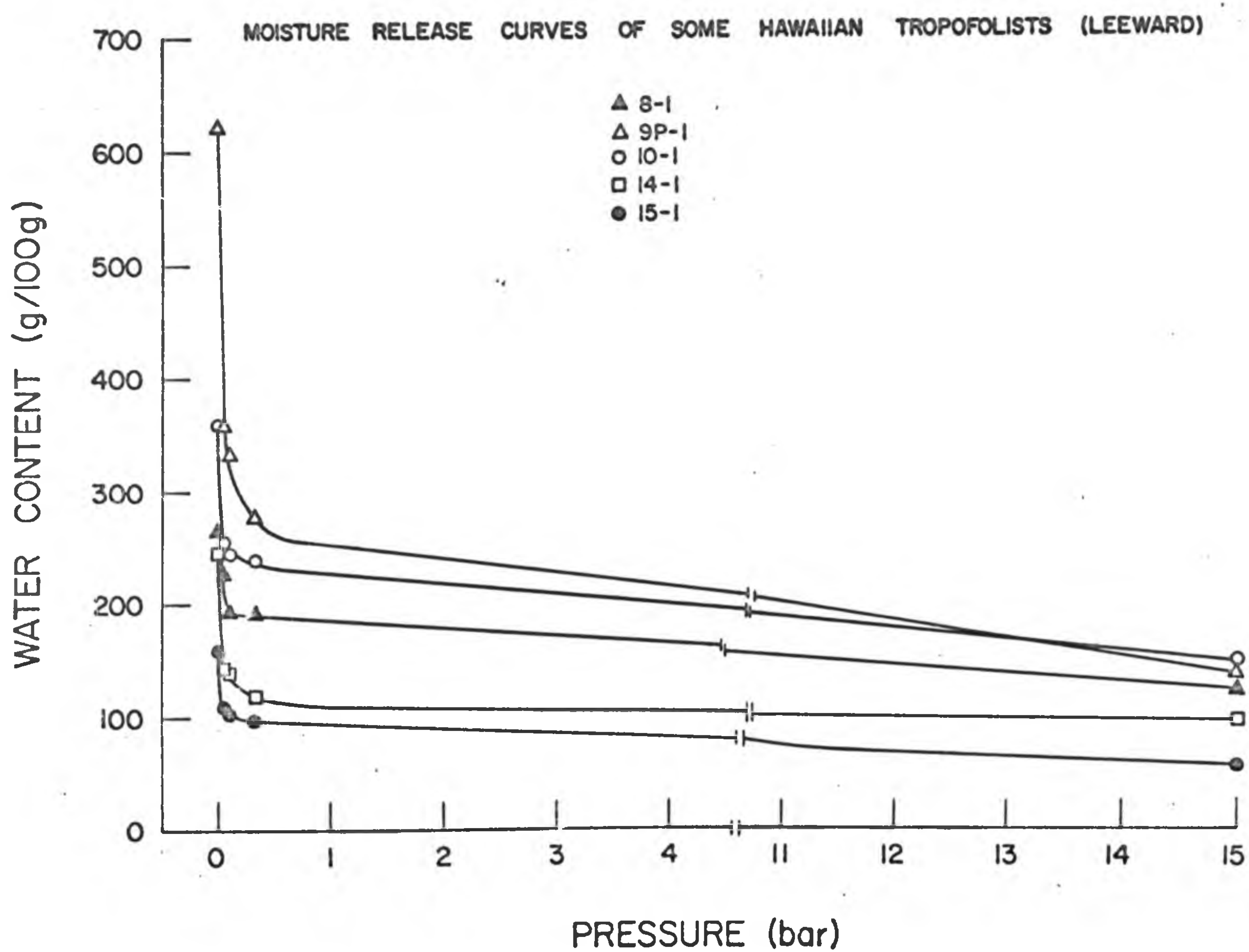
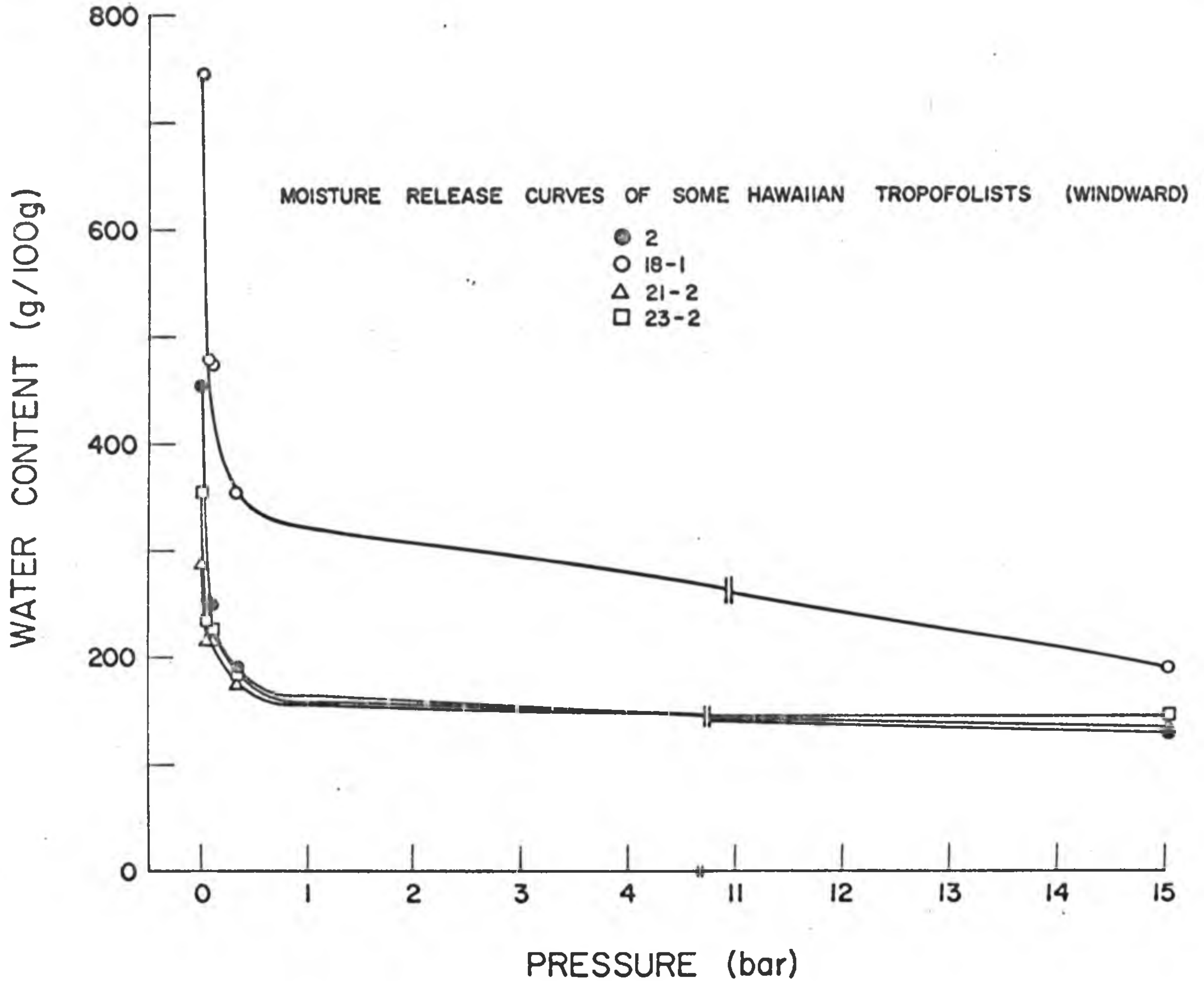

MOISTURE RELEASE CURVES OF SOME HAWAIIAN TROPOFOLISTS (LEEWARD)
8-1
9P-1
10-1
14-1
15-1
WATER CONTENT (g/100g)
700
600
500
400
300
200
100
0
0
1
2
3
4
11
12
13
14
15
PRESSURE (bar)

Figure 15. Moisture Release Curves of Some Hawaiian Tropofolists from the Windward Side

Sample No.	Elev. (m)	R.F. (cm)	Underlying Rocks	OM Content (%)	Moisture Condition
2	151	100-150	aa	73.43	wet
18-1	1,439	100-150	aa	80.87	wet
21-2	1,015	375-450	aa	16.67	wet
23-2	606	525-550	aa	37.22	wet


MOISTURE RELEASE CURVES OF SOME HAWAIIAN TROPOFOLISTS (WINDWARD)
2
18-1
21-2
23-2
WATER CONTENT (g/100g)
800
600
400
200
0
0
1
2
3
4
11
12
13
14
15
PRESSURE (bar)

large amounts of both large and small size pores as evidenced by the fact that they have high moisture contents at all values of equilibrium pressures. The second case reflects that differences between some samples, such as samples 8-1 and 14-1 (Figure 15), occur only in the amount of finer pores. This is evidenced by the fact that they contained almost equal amounts of water at saturation. It is important to emphasize, however, that the total volume of water retained by an organic material at high pressure may not be due only to the presence of fine pores but also to the presence of other forms of water associated with molecular groups either at the surface or within the structure of the material.

In spite of these differences, almost all of the moisture release curves were somewhat similar to those obtained for coarse-textured soils. These curves show that approximately one-third to one-half of the water content at saturation was released at a low tension equivalent to 1/20 bar. However, the similarity ends there because, except in few cases, only small additional amounts of water were released by increasing the tension to 15 bars. At this tension, the water content ranged from 55.52 to 263.69 per cent on an oven-dry weight basis. At the same tension, the water content of a coarse-textured mineral soil or sand is almost nil.

Four general factors appear to affect the water holding capacities of organic soils: (1) Dryness--These soils, as mentioned previously, dry irreversibly. It is not possible to rewet them after being thoroughly air dried and to obtain water retention values as high as those of undried samples. (2) Organic Matter Content--The amount and kind of clay minerals in mineral soils, more or less determine the content of water held in the soils. Similarly for organic soils, the amount and fineness of the organic matter should determine the amount of water held. However, organic matter existing in the form of fresh litter cannot account for the high water holding capacities of the soils at higher tension. Thus, the amount of water held in an organic soil reflects to a large extent the degree of decomposition of organic matter. In Hawaiian folists, the presence of small fragments of rocks in the organic layer can greatly influence the water holding capacity. These rock fragments behave like coarse-textured materials retaining very little or no water. (3) Rainfall and Temperature--Both of these climatic factors are associated with elevation and reflect the differences in microclimate which can affect water holding capacities insofar as they can influence soil hydration and the degree of decomposition. (4) Vegetation--According to Boelter (1964), the kind of decomposed vegetation being the source of organic materials, can greatly influence the water holding capacity of such soils.

It is interesting to note that results of this investigation showed no correlation between climate or elevation and the water holding capacity of the samples. The lack of such correlation may be due to the inverse relationship between rainfall distribution and elevation above the inversion layer and/or the short time of the organic deposits. Furthermore, two clear relationships were obtained between the degree of decomposition and water retention. These soils are easily drained and normally would not remain saturated were it not for their occurrence in small, poorly drained depressions above relatively impervious pahoehoe lava substratum. Therefore, the management of soils with such water retention properties would be quite different from other organic soils elsewhere.

It is also worthwhile to discuss the water retention properties of organic soils in terms of volumetric rather than gravimetric water contents. However, as mentioned previously, bulk density determination necessary for making such conversions were possible only in a few samples. The calculation of volumetric from gravimetric values was possible in Samples 18-1, 18-2, 20-2, 21-2, 22-1, 22-2, and 24-2. For these samples, water retention characteristics on volumetric basis were similar to those on a gravimetric basis although the modified data appear more realistic in terms of the relative water contents among samples (Table 8).

Bulk Density--Only a few samples from the Stainback Highway sequence were used to determine the bulk density because most of the other samples were loose and did not contain the clods needed for the determination. Table 7 shows that the bulk density values ranged from 0.13 to 0.32 g/cc. These values may be slightly high, for according to Tisdall (1951), the clod method does not take into account the inter-clod pore space.

In this study, the samples with higher values of bulk density were those containing the small fragments of rocks. The true bulk densities of these folists, therefore, may be nearer to the 0.10 g/cc (Table 7).

Fiber Content--The fiber content, according to the Soil Survey

TABLE 8. VOLUMETRIC WATER RETENTION OF SOME SAMPLES FROM STAINBACK HIGHWAY SEQUENCE

	Water Content (cc/100 cc)				
Sample No.	Saturation	1/20 bar	1/10 bar	1/3 bar	15 bar
18-1	125.34	62.43	61.78	43.55	24.84
18-2	93.67	60.77	59.16	47.37	34.28
20-1	97.66	71.32	69.53	46.91	24.77
21-2	77.97	58.16	59.12	47.73	36.42
22-1	125.05	95.68	95.48	72.25	49.21
22-2	97.28	67.13	63.09	49.55	32.06
24-2	85.54	60.35	59.05	56.03	45.25

Staff (1968), is an important measurable property which reflects the degree of decomposition of organic matter. Based on the fact that decomposed organic matter is of finer size than undecomposed matter, the wet sieving was prescribed by the Soil Survey Staff (1968) to separate the coarse and fine materials.

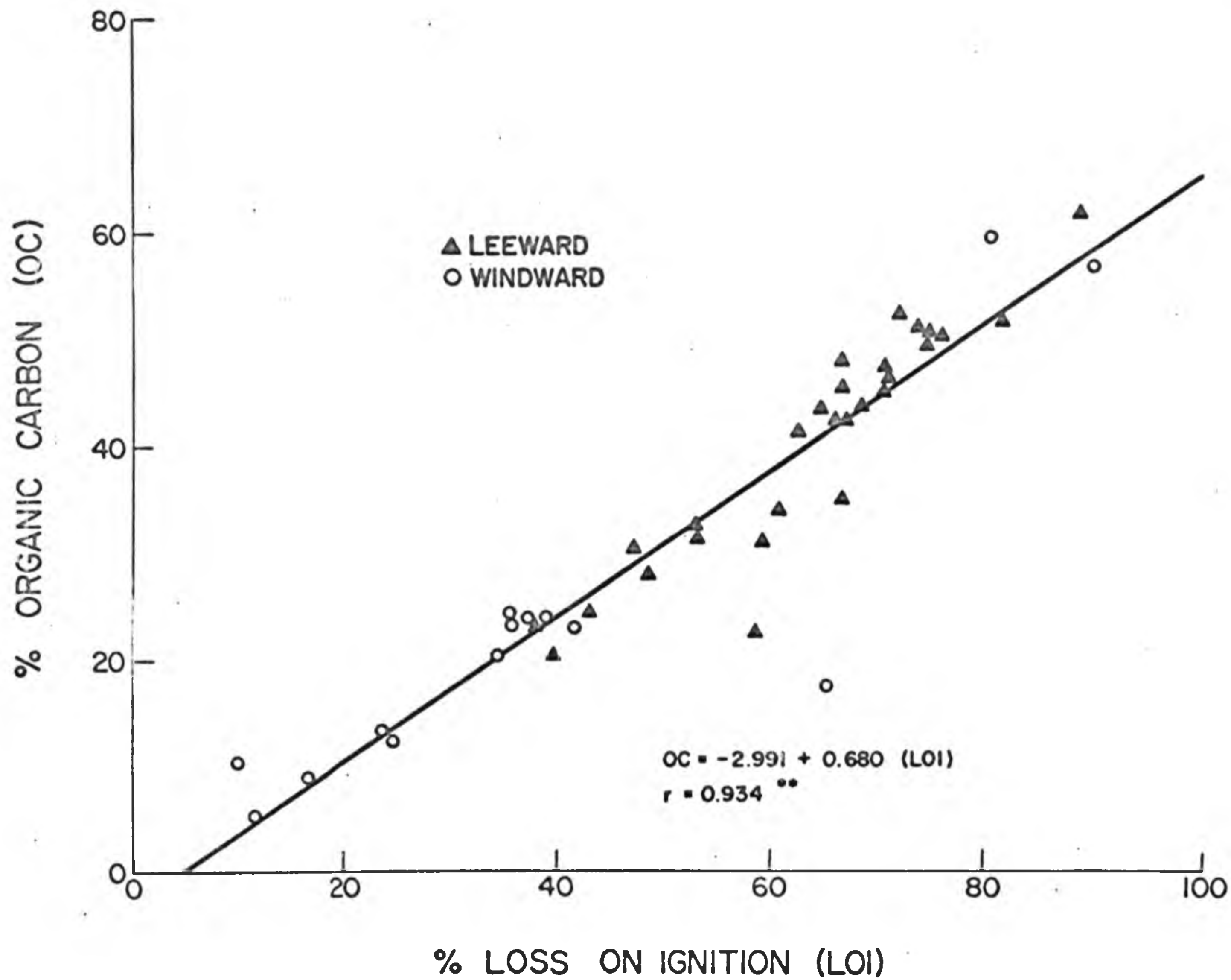
Two major problems were encountered when wet sieving was attempted. First, not only the fiber but also fragments of rocks and minerals such as volcanic ash and olivine, were retained on the sieve. Second, it was noted that even the well-decomposed organic soil materials, when dried, formed strong aggregates. These aggregates did not slake upon soaking in water and thus were retained on the sieve as coarser fractions together with the fibers. It is possible that this procedure for determining fiber content is more suitable for use in organic soils with greater depths (over 30 cm) than for these Folists (Soil Survey Staff, 1968). Thick organic layers are expected to have a more uniform composition in contrast to the thin organic layers in the Folists of this investigation.

For all these reasons, the determination of the fiber content is not recommended in the characterization of the Folists. The data on fiber contents of Tropofolists are not reported because of their unreliability.

Chemical Properties

Loss on Ignition (LOI)--In accordance with others (Farnham and Finney, 1965; Dolman and Buol, 1968; and Isirimah et al., 1970), loss on ignition was used as an estimate of organic matter content. As shown in Figure 16, there is a highly significant correlation

Figure 16. Regression of Per Cent Organic Carbon on Per Cent Loss on Ignition



% ORGANIC CARBON (OC)
80
60
40
20
0
LEEWARD
WINDWARD
OC = -2.991 + 0.680 (LOI)
r = 0.934 **
0
20
40
60
80
100
% LOSS ON IGNITION (LOI)

(r=0.934**) between LOI and oxidizable organic carbon which is another estimation of organic matter content. Tables 9, 10, and 11 show the loss on ignition values to range from 10 to 90 per cent. Some of the samples from the Stainback Highway sequence, Samples 20-1, 21-1, and 21-2, show organic matter contents as low as 10 per cent. Such values are below the value defined for organic soils, even though the samples were morphologically Histosols. Coarse to fine sized rocks and minerals were found incorporated with the organic soil material. The presence of such inorganic fragments was especially noted in samples which showed low values of LOI. The problem is more complicated in samples containing fragments of fresh basaltic rocks by the fact that oxidation of the Fe^{++} to Fe^{+++} iron during the LOI determination can easily account for increases in weight (Jackson, 1956). Two exceptions were noted in the Stainback Highway sequence for Samples 18-1 and 18-2, both of which exhibited high values of LOI. There were less rock fragments and there were less decomposed organic materials, as evidenced by their degree of decomposition and water retention data in these samples, and thus are expected to reflect low contents of ash as cited by Farnham and Finney (1965).

Organic Carbon--The term organic carbon used in this paper refers to the oxidizable organic carbon as determined by the Walkley-Black method and as described by the Soil Survey Staff (1967). In mineral soils, the content of organic matter is estimated from the per cent of organic carbon by multiplying the latter by a factor of 1.724 (the Van Bremmelen factor). Broadbent (1965) found that the value of this factor for the surface of mineral soils usually fell in the range of

TABLE 9. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--KEALAKEKUA SEQUENCE

Sample No.	LOI[a] (%)	Org. C. (%)	OM Org. C.	OM[b] (%)	Total N (%)	C/N	Absorbance	Degree of Decomposition[c]
5	74.53	49.83	1.4956	85.71	1.26	39	140	188 (M)
6	74.91	50.48	1.4839	86.82	1.27	40	114	152 (L)
7	67.67	48.09	1.4071	82.71	1.56	31	323	477 (H)
8-1	81.87	51.85	1.5789	89.18	2.38	22	243	303 (M)
8-2	76.21	50.08	1.5217	86.14	2.21	23	223	293 (M)
9A-1	72.00	52.32	1.3761	89.99	1.61	33	100	139 (L)
9A-1	47.34	30.83	1.5355	53.03	1.44	21	155	327 (M)
9P-1	66.68	45.72	1.4584	78.64	1.33	34	190	285 (M)
9P-2	70.46	47.48	1.4839	81.66	1.52	31	221	314 (M)
10-1	67.23	42.77	1.5718	73.56	2.04	14	134	199 (M)
10-2	66.49	35.18	1.8899	60.51	1.89	19	157	236 (M)
11-1	53.38	32.94	1.6205	56.66	1.36	24	182	341 (H)
11-2	66.23	42.65	1.5528	73.36	1.85	23	212	320 (M)
12-1	38.39	23.30	1.6476	40.94	1.04	23	88	229 (M)
12-2	60.09	34.19	1.7575	58.81	1.61	21	164	269 (M)
13-1	53.05	31.59	1.6793	54.33	1.82	17	147	277 (M)
13-2	48.81	27.90	1.7494	47.99	1.71	16	115	236 (M)
14-1	70.43	45.72	1.5404	78.64	1.99	23	104	147 (L)
14-2	71.61	46.87	1.5278	80.62	1.18	40	107	149 (L)

[a]LOI = Loss on Ignition

[b]OM = Organic Matter (Org. C x 1.72)

[c]Relative degree of decomposition expressed as low (L), medium (M) or high (H) according to absorbance of pyrophosphate extracts adjusted to correct for organic matter content in the samples.

TABLE 10. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--KAINALIU SEQUENCE

Sample No.	LOI[a] (%)	Org. C. (%)	OM Org. C.	OM[b] (%)	Total N (%)	C/N	Absorbance	Degree of Decomposition[c]
16-1	59.08	31.36	1.8839	53.59	2.95	11	205	347 (H)
16-2	87.62	61.92	1.4150	106.50	2.35	26	101	115 (M)
15-1	58.47	22.82	2.5622	39.25	1.41	16	166	284 (M)
15-2	68.20	44.87	1.5199	77.87	1.92	23	197	283 (M)
17-1	39.66	20.84	1.9030	35.84	1.19	17	119	300 (M)
17-2	43.03	24.84	1.7322	42.72	1.16	21	70	202 (M)

[a]LOI = Loss on Ignition

[b]OM = Organic Matter (Org. C x 1.72)

[c]Relative degree of decomposition expressed as low (L), medium (M), or high (H) according to absorbance of pyrophosphate extracts adjusted to correct for organic matter content in the samples.

TABLE 11. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--STAINBACK HIGHWAY SEQUENCE

Sample No.	LOI[a] (%)	Org. C. (%)	OM Org. C.	OM[b] (%)	Total N (%)	C/N	Absorbance	Degree of Decomposition[d]
18-1	80.87	59.57	1.3595	102.41	1.38	43	70	86 (L)
18-2	90.10	56.72	1.5885	97.56	1.75	32	93	103 (L)
19-1	35.97	23.55	1.5273	40.51	0.94	25	91	253 (M)
19-2	35.54	24.68	1.4400	42.85	1.81	13	60	168 (L)
20-1	10.61	10.84	0.9787	18.64	0.58	19	60	565[c] (H)
20-2	65.13	17.38	3.7474	29.89	0.74	23	89	136 (L)
21-1	11.47	5.23	2.1931	8.99	0.26	20	34	296 (M)
21-2	16.67	9.12	1.8278	15.68	0.90	10	87	521[c] (H)
22-1	41.78	23.37	1.7877	40.19	0.52	45	104	251 (M)
22-2	23.50	13.84	1.6978	23.80	0.65	21	63	268 (M)
23-1	24.61	12.98	1.8959	22.32	1.13	11	99	402 (H)
23-2	37.22	24.05	1.5476	41.37	1.03	23	143	384 (H)
24-1	34.22	20.99	1.6303	36.10	0.89	23	96	280 (M)
24-2	39.15	24.41	1.6039	41.98	0.93	26	82	209 (M)
1	63.41	41.91	1.5130	72.08	1.41	30	88	139 (L)
2	73.43	51.40	1.4285	88.41	1.36	38	156	212 (M)
4	64.79	43.96	1.4738	75.61	1.52	29	78	120 (L)

[a]LOI = Loss on Ignition

[b]OM = Organic Matter (Org. C x 1.72)

[c]See Discussion

[d]Relative degree of decomposition expressed as low (L), medium (M) or high (H) according to absorbance of pyrophosphate extracts adjusted to correct for organic matter content in the samples.

1.8-2.0. For organic soils, however, there seems to be little available information as to the best applicable factor. By using the factor of 1.724 to estimate the per cent organic matter in this study, it was found that a few soils had values exceeding 100 per cent.

Assuming that experimental errors were negligible, a new factor for Tropofolists used in this study was derived using the equation:

Factor = Per cent organic matter ÷ Per cent organic C

This was done to check the assumption that organic matter contains 58 per cent carbon. The Van Bremmelen factor of 1.724 makes this assumption and is commonly used to calculate per cent organic matter as follows:

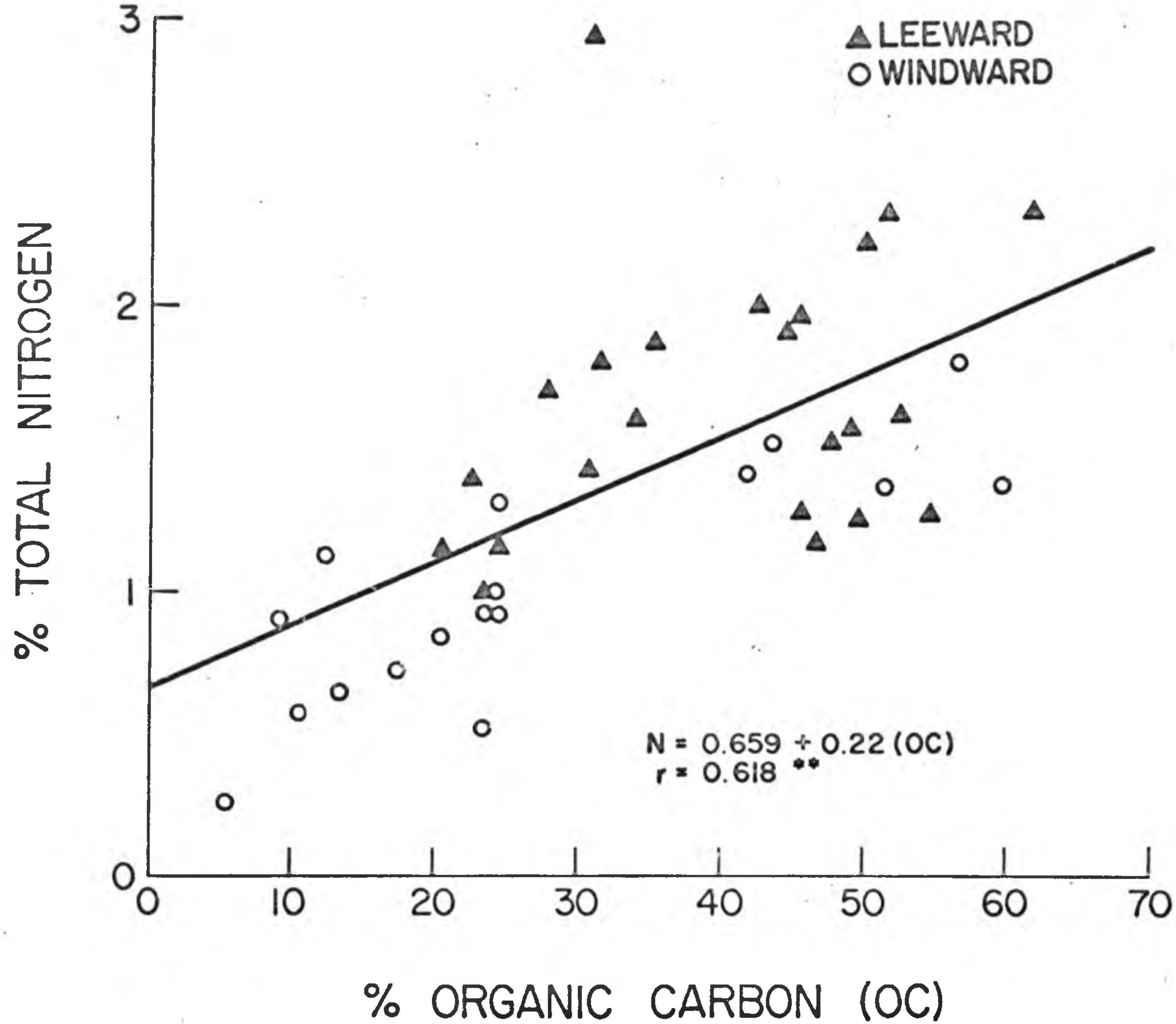
Per cent organic matter = 1.724 x Per cent organic C

Figure 16 was used to calculate a suitable factor for this conversion based on the results of the samples under study. This average value for factor was found to be 1.471, which is appreciably lower than the universal Van Bremmelen factor. However, a wide range of the factors for different samples were found. The range fell between 0.9787 and 3.7474, indicating wide variations of per cent carbon in these samples.

The organic carbon values ranged from 5 to 61 per cent. These values showed a positive correlation with LOI (r=0.934**), with total nitrogen (r=0.618**) and with Absorbance (r=0.418**).

The regression curves and equations are shown in Figures 16, 17, and 18.

Figure 17. Regression of Per Cent Total Nitrogen on Per Cent Organic Carbon



LEEWARD
WINDWARD
N = 0.659 ÷ 0.22 (OC)
r = 0.618 **
% TOTAL NITROGEN
% ORGANIC CARBON (OC)

Total Nitrogen and C/N ratio--The values of total nitrogen ranged from 0.26 to 2.95 per cent. These values lie within the range of peat soils cited by Bremner (1965). The results show that the samples on the leeward side possess higher values of total nitrogen than those on the windward side. These findings agree with those of Fukunaga and Dean (1939) as cited by Ayre (1943). These two investigators found that some mineral soils of humid regions release nitrogen more rapidly than soils in the drier regions. The released nitrogen becomes subject to more use by plants and more loss by leaching. Total nitrogen showed positive correlation with organic carbon as expected and as cited earlier (r=0.618**).

The carbon-nitrogen ratio varied from 10 to 45. The results are presented in Tables 9, 10, and 11. The tables showed that organic carbon and total nitrogen contents are higher in the leeward than the windward side. Judging from the data, higher C/N ratios are also encountered in the leeward side. This trend is opposite to that expected in mineral soils. Ayres (1943) reported that C/N ratios in organic components of volcanic soils increased with decreasing rainfall. However, the trends reported in this study appear to follow what would be expected in organic soils, namely C/N ratios should increase as increasing degree of decomposition. This is supported by the fact that the degree of decomposition of samples from the windward side appears to be higher than that of samples from the leeward side.

It is interesting to note that the organic carbon contents were found to be higher in the leeward side probably due to the presence of charcoal fragments in these samples. Presumably these charcoal came about as a result of the occurrence of forest fires.

Absorbance and Degree of Decomposition--The data on absorbance and degree of decomposition are also shown in Tables 8, 10, and 11. The results vary from 34 to 325 (0.34 to 3.24 per cent) for absorbance and 86 to 565 (0.86 to 5.65 per cent) for the degree of decomposition, respectively.

The product of organic matter decomposition can be obtained by extracting the organic acid with a dilute pyrophosphate solution (MacLean et al., 1964). The most widely used method and the method used in this study, is the one proposed by Kaila (1956). The absorbance was expressed as a whole number after multiplying the per cent absorbance by 100. This procedure was used by many investigators to obtain an index of degree of decomposition (e.g., Schnitzer and Hoffman, 1966). In this study, due to the presence of small fragments of rocks and some primary minerals in some of the samples, it was not possible in every case to compare the absorbance of one sample with another. The absorbance reading, therefore, was recalculated to account for the content of the decomposed organic matter in the samples. The resulting values for degrees of decomposition were obtained by dividing the original absorbance readings by the weight of organic matter rather than the weight of the entire sample.

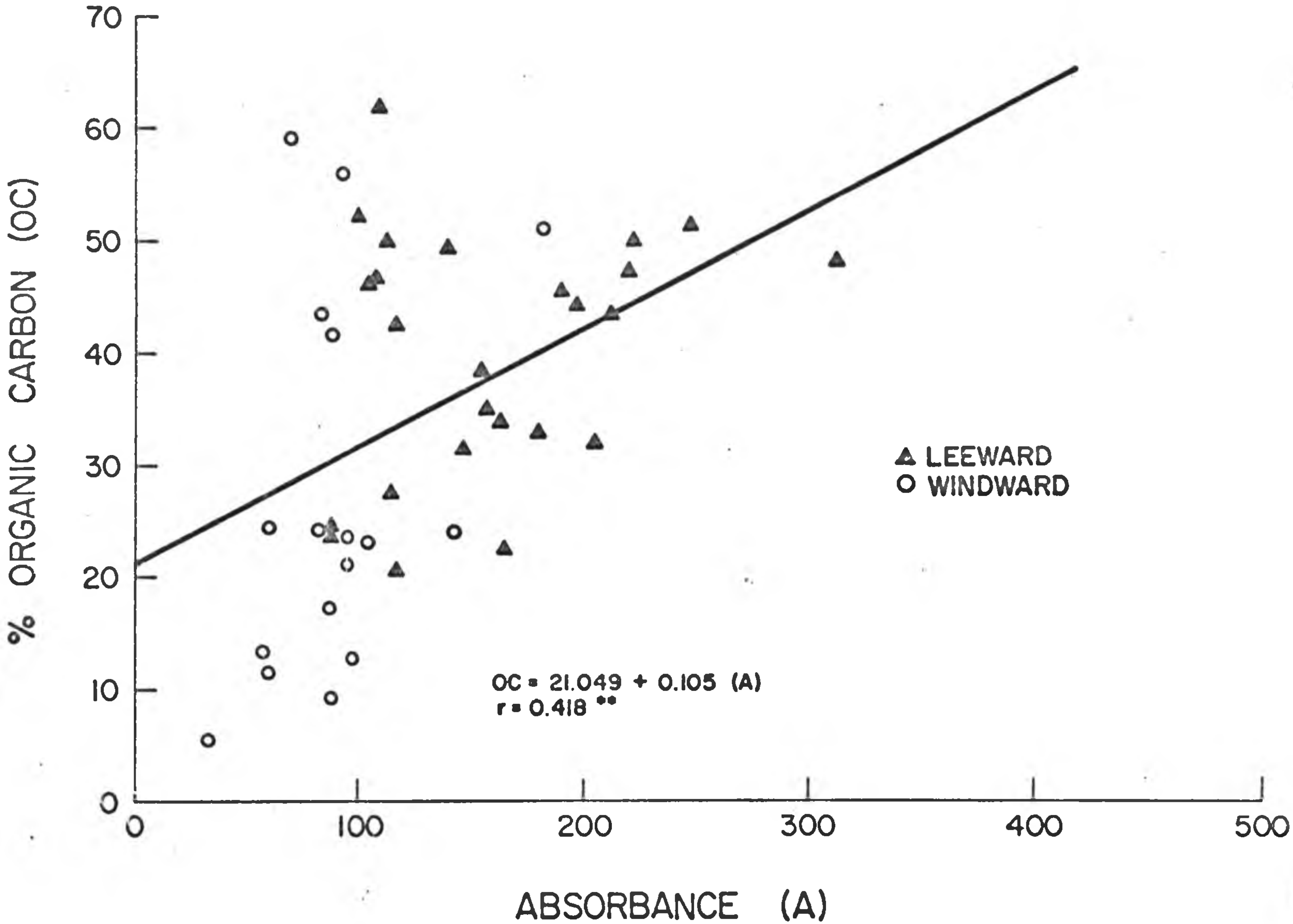
The results of the adjusted absorbance, or the degree of decomposition, were arbitrarily divided into three groups. Samples with values of less than 170 were classified as least decomposed (L), from 170 to 330 as moderately decomposed (M), and those with the values of over 330 as highly decomposed (H). The results show that the majority of the samples, 18 out of 25, on the leeward side, the Kealakekua and the Kainaliu sequences, fell into the category of moderate degree of decomposition. Five of the 25 samples were in the category of least degree of decomposition, and three were at the highest level. For the windward side, or the Stainback Highway Sequence, nearly equal numbers of samples fell into the least and moderate categories. Only four samples fell within the highest degree of decomposition. However, the results of two samples were unusually high. Samples 20-1 and 21-2 showed high values of absorbance probably because of their high amount of organic matter contents as discussed previously. Most samples from the leeward side appear to be more decomposed than those from the windward side. This is despite the fact that the average degree of decomposition from the leeward and windward sides were 257 and 258, respectively. The average value of degree of decomposition for the windward sample drops to 220 when values for Samples 20-1 and 21-2 are not included in the calculation. It may be recalled that the findings reported on the C/N ratios also support the conclusion that samples from the leeward side have higher degrees of decomposition than those from the windward side.

Pyrophosphate extract absorbances are shown to be correlated with organic carbon (r=0.418**). However, the plotted values (Figure 18) show much scatter. The regression equation is as follows:

$$\text{Per cent Organic C} = 21.049 + 0.105 \times \text{Absorbance}$$

According to the data in Tables 12, 13, and 14, all samples are

Figure 18. Regression of Per Cent Organic Carbon on Absorbance



% ORGANIC CARBON (OC)
ABSORBANCE (A)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
LEEWARD
WINDWARD
OC = 21.049 + 0.105 (A)
r = 0.418 **

TABLE 12. FIELD AND LABORATORY DATA ON DEGREE OF DECOMPOSITION OF TROPOFOLISTS--KEALAKEKUA SEQUENCE

Sample No.	Mapping Unit		Color Sat. Na. pyrophosphate	Degree of Decomposition
5	rLW	Lava flow pahoehoe	7.5YR 4/4	188 (M)
6	rLW	Lava flow pahoehoe	10YR 4/3	152 (L)
7	rMWD	Mawae extremely stony muck	7.5YR 3/2	477 (H)
8-1	rMWD	Mawae extremely stony muck	7.5YR 4/4	303 (M)
8-2			7.5YR 4/4	293 (M)
9A-1	rKXD	Kiloa extremely rocky muck	10YR 6/3	139 (L)
9A-2			10YR 6/3	327 (M)
9P-1	rMWD	Mawae extremely stony muck	10YR 6/3	285 (M)
9P-2			7.5YR 4/4	314 (M)
10-1	rKXD	Kiloa extremely rocky muck	10YR 6/3	199 (M)
10-2			10YR 6/3	236 (M)
11-1	rPXE	Puna extremely stony muck	10YR 6/4	341 (M)
11-2			10YR 5/4	320 (M)
12-1	rPXE	Puna extremely stony muck	10YR 6/3	229 (M)
12-2			10YR 6/3	269 (M)
13-1	rPYD	Punaluu extremely stony peat	10YR 6/3	277 (M)
13-2			10YR 6/3	236 (M)
14-1	rLV	Lava flow aa	10YR 6/3	147 (L)
14-2			10YR 6/3	149 (L)

TABLE 13. FIELD AND LABORATORY DATA ON DEGREE OF DECOMPOSITION OF TROPOFOLISTS--KAINALIU SEQUENCE

Sample No.	Mapping Unit		Color Sat. Na. pyrophosphate	Degree of Decomposition
16-1	rKHD	Kekake extremely rocky muck	7.5YR 4/4	347 (H)
16-2			7.5YR 4/4	115 (L)
15-1	rKHD	Kekake extremely rocky muck	7.5YR 4/4	284 (M)
15-2			7.5YR 3/2	288 (M)
16-1	rKHD	Kekake extremely rocky muck	10YR 4/4	300 (M)
16-2			10YR 6/3	202 (M)

TABLE 14. FIELD AND LABORATORY DATA ON DEGREE OF DECOMPOSITION OF TROPOFOLISTS--STAINBACK HIGHWAY SEQUENCE

Sample No.	Mapping Unit		Color Sat. Na. pyrophosphate	Degree of Decomposition
18-1	rKAD	Kahaluu extremely rocky muck	10YR 6/3	86 (L)
18-2			10YR 6/3	103 (L)
19-1	rLLD	Lalaau extremely stony muck	10YR 6/4	253 (M)
19-2			10YR 6/3	168 (L)
20-1	rLLD	Lalaau extremely stony muck	10YR 6/3	565 (H)
20-2			10YR 6/3	136 (L)
21-1	rKXD	Kiloa extremely rocky muck	10YR 6/3	296 (M)
21-2			10YR 6/3	521 (H)
22-1	rKXD	Kiloa extremely rocky muck	10YR 5/4	251 (M)
22-2			10YR 6/3	268 (M)
23-1	rKXD	Kiloa extremely rocky muck	10YR 6/3	402 (H)
23-2			10YR 6/3	384 (H)
24-1	rKFD	Keaukaha extremely rocky muck	10YR 6/3	280 (M)
24-2			10YR 6/3	209 (M)
1	rKFD	Keaukaha extremely rocky muck	10YR 6/3	139 (L)
2	rPAE	Papai extremely rocky muck	7.5YR 4/4	212 (M)
4	rPAE	Papai extremely rocky muck	10YR 5/4	120 (L)

considered to be at the highest stage of decomposition. A similar conclusion is also reached when these data are compared with those of Schnitzer and Hoffman (1966). These authors considered samples with absorbance values of 60 or more to be muck. It is to be concluded that despite the relative decomposition categories assigned to the samples of this study, these are all so highly decomposed that this parameter is not as useful for use in their classification as for the classification of temperate zone soils. This may also account for the difficulty encountered earlier in establishing a relationship between the degree of the decomposition and water retention.

Humic Acid (H), Fulvic Acid (F), and Humic-Fulvic Ratio (H/F)--According to Tables 15, 16, and 17, humic acid values ranged from 0.15 to 26.47 per cent, and the fulvic acid values from 4.05 to 24.55 per cent. No significant trends were observed between fulvic acid values or the humic-fulvic ratios and other properties. A plot of humic acid against absorbance (Figure 19) shows quite a scatter. Nevertheless, there is a positive correlation between humic acid and absorbance (r=0.552**). This indicates, in agreement with findings of other investigators, that the production of humic acid increases as the degree of decomposition increases.

Aside from being used as an index to measure the degree of decomposition, humic acid can also be shown to have some effects on plant growth. Using solution cultures, de Kock (1955) found that humic acid influenced the content of iron in plants. These acids aided plant growth by making the iron in the nutrient solution readily available by a chelation mechanism similar to that attributed

TABLE 15. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--KEALAKEKUA SEQUENCE (Cont.)

Sample No.	Humic Acid (H) (%)	Fulvic Acid (F) (%)	H/F	pH (1:1) in H_2O	KCl	0.01 M $CaCl_2$	Delta pH $pH_{KCl} - pH_{H_2O}$
5	20.29	15.04	1.34	5.24	4.41	4.95	-0.83
6	12.34	14.38	0.96	4.78	4.00	4.68	-0.78
7	20.43	14.27	1.42	4.13	4.16	4.68	+0.03
8-1	26.47	13.02	2.09	4.35	3.90	4.18	-0.45
8-2	18.12	17.93	1.01	4.28	3.88	4.12	-0.40
9A-1	6.77	10.06	0.68	4.18	4.63	4.90	+0.45
9A-2	2.08	8.70	0.27	6.07	5.32	5.52	-0.75
9P-1	5.86	17.46	0.37	4.22	4.50	4.82	+0.28
9P-2	5.94	10.81	0.58	4.57	3.98	4.26	-0.59
10-1	8.49	22.19	0.37	5.21	4.70	4.88	-0.41
10-2	9.69	19.97	0.48	5.56	5.04	5.30	-0.52
11-1	8.16	14.03	0.58	5.51	4.78	5.00	-0.60
11-2	13.97	20.04	0.69	5.34	4.91	5.03	-0.43
12-1	2.60	7.14	0.33	5.82	5.20	5.42	-0.62
12-2	5.67	12.04	0.46	5.69	5.01	5.30	-0.68
13-1	7.64	9.46	0.89	5.96	5.21	5.74	-0.75
13-2	2.66	10.86	0.24	6.21	5.59	5.74	-0.62
14-1	10.41	11.39	0.68	5.01	5.41	5.76	+0.40
14-2	15.42	15.02	0.78	6.24	5.56	5.91	-0.68

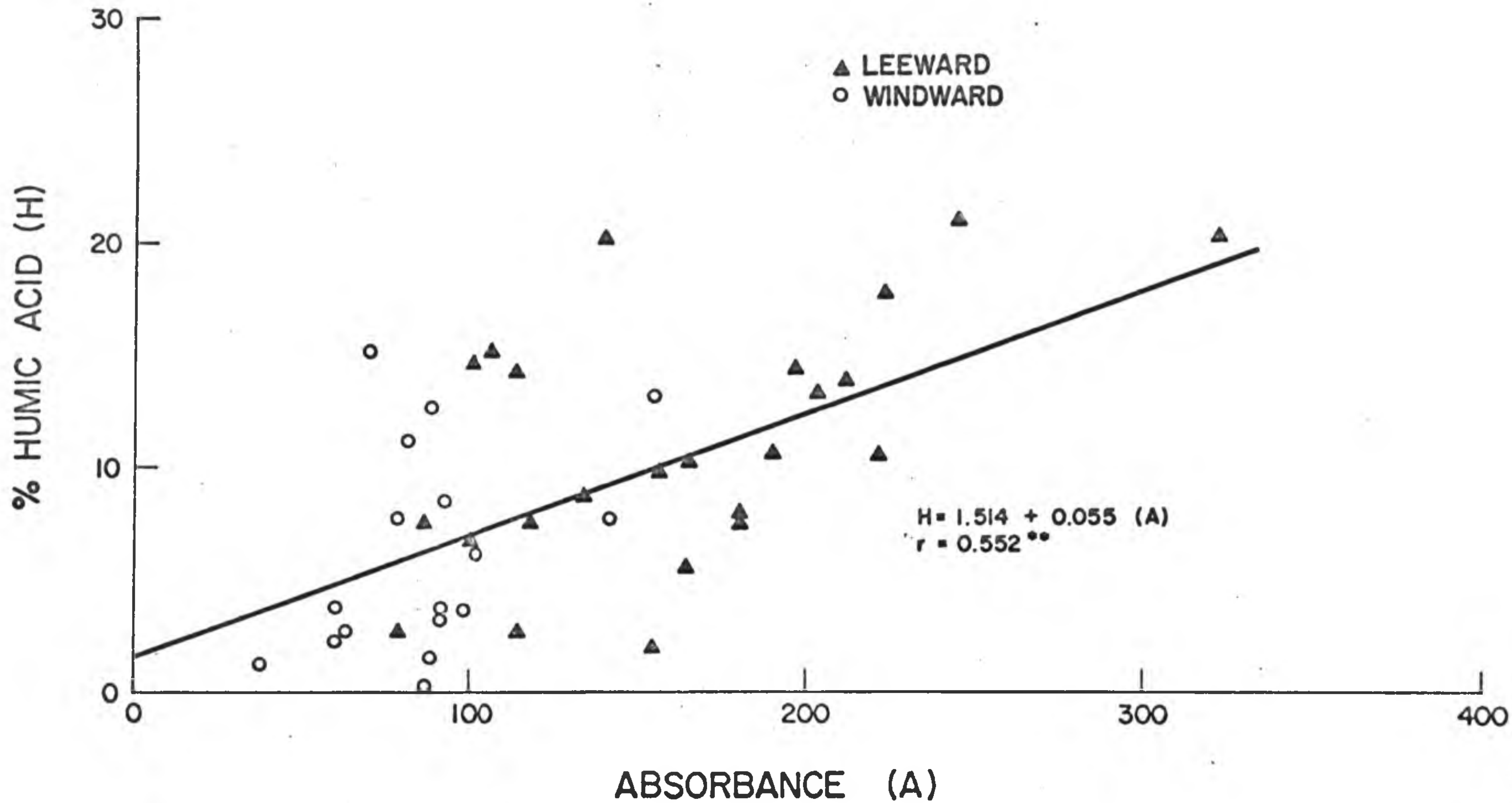
TABLE 16. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--KAINALIU SEQUENCE (Cont.)

Sample No.	Humic Acid (H) (%)	Fulvic Acid (F) (%)	H/F	pH (1:1) in H_2O	pH (1:1) in KCl	pH (1:1) in 0.01 M $CaCl_2$	Delta pH $pH_{KCl} - pH_{H_2O}$
16-1	8.80	9.38	0.93	5.20	4.54	4.72	-0.66
16-2	14.53	10.36	1.35	5.55	4.66	5.10	-0.99
15-1	5.39	6.27	0.57	5.29	4.58	4.37	-0.71
15-2	14.92	12.26	1.58	4.60	4.00	4.72	-0.60
17-1	7.26	12.98	0.48	5.81	5.18	5.52	-0.63
17-2	5.74	12.40	0.63	5.70	5.20	5.48	-0.50

TABLE 17. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--STAINBACK HIGHWAY SEQUENCE (Cont.)

Sample No.	Humic Acid (H) (%)	Fulvic Acid (F) (%)	H/F	pH (1:1) in H_2O	KCl	0.01 M $CaCl_2$	Delta pH $pH_{KCl} - pH_{H_2O}$
18-1	15.39	24.55	0.63	4.44	3.66	3.85	-0.78
18-2	8.85	10.28	0.88	3.76	3.24	3.51	-0.52
19-1	3.28	10.13	0.29	4.21	4.56	4.79	+0.35
19-2	3.89	10.21	0.37	5.72	4.95	5.16	-0.77
20-1	2.37	9.24	0.26	5.11	4.55	4.67	-0.56
20-2	1.57	15.11	0.12	5.59	4.76	5.08	-0.83
21-1	1.38	4.68	0.28	5.44	4.66	4.79	-0.78
21-2	0.15	4.05	0.03	5.44	4.66	4.92	-0.78
22-1	6.43	14.34	0.43	4.96	4.31	4.50	-0.65
22-2	2.72	9.22	0.29	5.48	4.70	4.90	-0.78
23-1	3.72	7.51	0.46	5.44	4.69	4.81	-0.75
23-2	7.71	12.10	0.66	5.35	4.48	4.71	-0.87
24-1	3.57	12.29	0.29	5.00	4.32	4.46	-0.68
24-2	11.24	15.13	0.72	5.25	4.54	4.83	-0.71
1	13.12	10.53	1.24	4.28	4.23	4.52	-0.05
2	13.40	13.01	0.93	4.21	3.77	4.06	-0.44
4	7.76	6.68	1.16	5.26	4.61	5.12	-0.65

Figure 19. Regression of Per Cent Humic Acid on Absorbance



▲ LEEWARD
○ WINDWARD
H= 1.514 + 0.055 (A)
r = 0.552 **
% HUMIC ACID (H)
ABSORBANCE (A)
0
10
20
30
0
100
200
300
400

by Fe-EDTA and by promoting its translocation to leaves.

pH--Tables 15, 16, and 17 show that the samples are acidic, as the pH in water ranged from 3.76 to 6.24, the pH in 1 N KCl ranged from 3.24 to 5.59, and that in 0.01 M $CaCl_2$ solution ranged from 3.51 to 5.91. The delta pH, which is the difference between pH in KCl and in water, ranged from -0.83 to +0.45.

Organic material in soils is composed of an extremely complicated array of products arising from partially decomposed to decomposed plants. Sherman and Kanehiro (1948) reported the pH values of leaf moulds of *Metrosideros* and *Dicranopteris* to be 3.9 and 3.8, respectively. Atkinson (1969) reported the pH values of the former to be 4.05. He also reported that the pH of *Cibotium* spp. and *Pandandus tectorious* to be 3.82 and 7.10, respectively. There is also general agreement among many investigators, as mentioned in the Review of Literature, that the acid functional groups of organic matter are carboxyls, phenols, enols, or other alcoholic hydroxyl groups. The relative amount of each of these groups appears to vary with both the soils and the organic fraction.

For mineral soils, it is generally known that the effect of salt concentration on pH is mainly due to ion exchange phenomena. Tables 15, 16, and 17 show that when salt solutions of KCl and $CaCl_2$ are used, the pH values of the samples tend to be lower than those determined with water. Only four samples exhibited position delta pH, i.e., showed higher pH in KCl solutions and in $CaCl_2$ solutions than in water. In mineral soils, this effect is attributed to net positive charges contributed by iron and aluminum oxides. For organic soils the net positive charge might be also due to the presence of positive charges, a possible reason for their abilities to fix phosphorus.

The data also shows a direct correlation between sample pH determined in $CaCl_2$ solution and base saturation. Generally, it is known that the measurement of pH in 0.01 M $CaCl_2$ solutions appear to provide a reasonably good index of calcium saturation in mineral soils. However, there are no similar studies for organic soils. More research in this area of research is warranted since the results would be quite important in evaluating the productivities of these soils.

Cation Exchange Capacity (CEC)--The cation exchange capacities at pH 4 and pH 7 are also shown in Tables 18, 19, and 20. Although few of the samples show similar CEC values at pH 4 and 7, most of them show higher values at pH 7. There is a wide range in the CEC values from 70.78 to 353.53 meq/100 g on oven-dry basis. The lower CEC values appear to be due to the lower amount of organic matter in some samples. There is, however, a highly significant correlation (r=0.680**) between CEC and LOI (Figure 20). Variations in the functional groups as discussed previously, may also account for some of the observed differences. On the other hand, the higher values at pH 7 can be attributed to the pH-dependence of charges associated with these soils (Buckman and Brady, 1969). Organic materials are known to exhibit significant amphoteric behavior.

It may be noted that the results show no differences in CEC between the windward and leeward sides.

TABLE 18. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--KEALAKEKUA SEQUENCE (Cont.)

Sample No.	CEC (meq/100 g) pH 4	CEC (meq/100 g) pH 7	Delta CEC pH 7 - pH 4	Exch. Bases (meq/100 g) Ca	Mg	K	Na	Total Bases	BS pH 4 (%)	BS pH 7 (%)
5	118.82	216.61	97.79	85.13	2.55	4.10	2.05	93.83	83.17	43.32
6	153.89	162.41	8.52	20.60	2.04	2.78	0.83	26.25	17.58	16.16
7	108.12	154.85	46.83	-	5.05	1.76	0.85	-	-	-
8-1	159.47	215.03	55.56	41.27	2.18	2.01	0.76	46.22	28.99	21.49
8-2	101.19	139.16	37.97	31.10	2.56	1.30	0.54	35.50	35.08	25.51
9A-1	118.19	174.22	56.03	69.96	2.72	4.26	1.54	78.48	63.86	45.05
9A-2	96.17	156.43	59.66	52.82	3.11	1.37	0.47	57.77	60.07	36.93
9P-1	113.29	191.33	78.04	55.32	1.12	2.93	1.40	60.77	28.03	31.76
9P-2	113.48	174.15	60.67	18.94	2.82	2.29	1.41	25.56	22.43	14.62
10-1	184.20	227.80	43.60	105.04	2.61	5.11	1.21	14.47	61.98	50.52
10-2	133.66	180.05	66.39	54.50	1.39	1.29	0.73	57.91	50.95	32.16
11-1	102.00	154.74	52.74	63.94	1.77	2.85	0.29	68.21	66.87	44.49
11-2	173.15	225.55	78.29	48.66	4.23	2.45	0.87	56.21	32.46	24.92
12-1	65.99	112.38	46.39	23.31	1.86	0.57	0.28	26.02	39.43	23.15
12-2	180.88	205.23	24.35	42.22	2.01	0.62	0.33	45.18	24.98	22.01
13-1	109.89	135.50	25.61	61.11	1.58	3.47	0.43	66.59	60.60	49.14
13-2	93.34	136.40	43.06	49.50	0.72	3.41	0.29	53.92	57.77	39.53
14-1	112.37	153.79	41.42	83.41	1.87	3.43	0.89	89.60	79.78	58.26
14-2	116.51	171.65	55.14	80.97	1.12	2.91	1.09	89.09	33.89	50.15

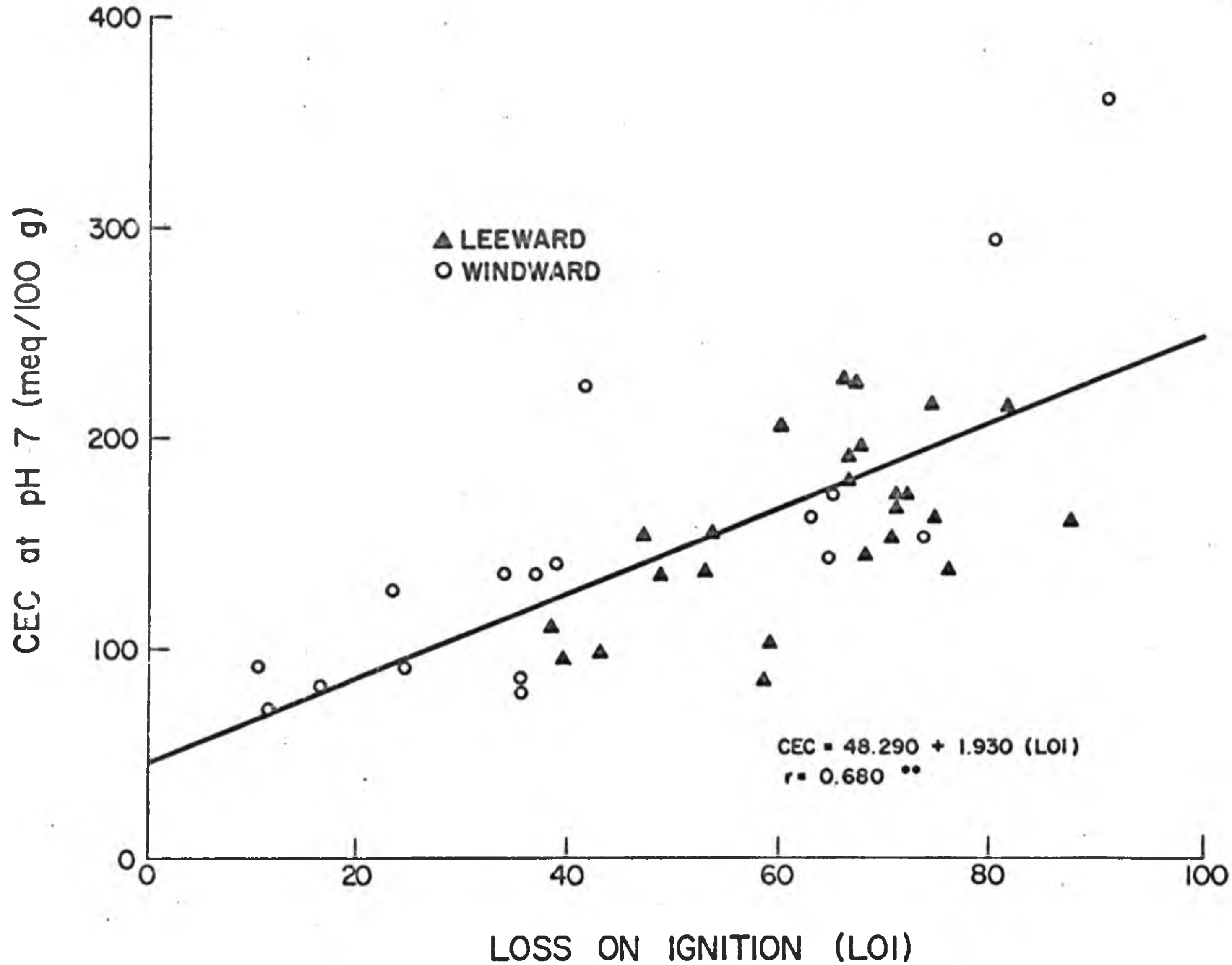
TABLE 19. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--KAINALIU SEQUENCE (Cont.)

Sample No.	CEC (meq/100 g) pH 4	CEC (meq/100 g) pH 7	Delta CEC pH 7 - pH 4	Exch. Bases (meq/100 g) Ca	Mg	K	Na	Total Bases	BS pH 4 (%)	BS pH 7 (%)
16-1	79.74	102.23	22.49	56.13	0.87	-	-	-	-	-
16-2	141.00	160.26	19.26	95.28	1.80	1.69	1.41	100.18	71.05	65.50
15-1	56.42	87.85	31.43	31.32	1.49	0.63	0.43	33.54	59.45	38.40
15-2	104.01	147.13	43.12	38.39	2.64	1.28	1.11	54.00	51.91	36.70
17-1	84.03	89.22	5.19	45.51	1.86	1.28	0.42	49.07	58.39	55.00
17-2	80.99	99.58	18.59	57.81	1.79	1.80	0.67	62.06	76.63	62.86

TABLE 20. CHEMICAL PROPERTIES OF HAWAIIAN TROPOFOLISTS--STAINBACK HIGHWAY SEQUENCE (Cont.)

Sample No.	CEC (meq/100 g) pH 4	CEC (meq/100 g) pH 7	Delta CEC pH 7 - pH 4	Exch. Bases (meq/100 g) Ca	Mg	K	Na	Total Bases	BS pH 4 (%)	BS pH 7 (%)
18-1	216.63	294.29	77.66	52.84	5.51	0.77	1.38	60.50	27.93	20.26
18-2	237.91	353.53	115.62	45.49	4.17	2.94	1.05	53.65	22.55	15.17
19-1	76.94	79.94	-	15.03	1.76	1.04	0.24	18.07	23.48	22.60
19-2	62.28	85.85	23.57	26.28	3.10	0.57	0.46	30.41	48.83	35.42
20-1	78.26	93.48	15.22	21.73	2.54	0.41	0.15	24.83	31.73	26.56
20-2	165.16	174.20	8.54	27.60	2.84	0.85	0.50	23.71	19.25	18.25
21-1	-	70.78	-	20.27	1.87	1.27	0.30	23.41	-	33.50
21-2	-	83.02	-	8.63	2.35	0.40	0.24	11.63	-	14.00
22-1	131.59	226.21	94.82	26.30	3.44	1.15	0.76	31.65	24.05	14.00
22-2	-	127.15	-	44.78	2.40	1.17	0.51	48.86	-	38.12
23-1	76.81	90.34	13.53	6.57	1.95	0.29	0.22	9.03	11.76	10.00
23-2	-	137.97	-	18.95	2.57	0.18	0.33	22.03	-	16.19
24-1	-	136.60	-	17.22	2.36	0.25	0.69	20.52	-	15.02
24-2	108.33	140.06	31.73	15.59	2.86	0.28	0.49	19.22	17.74	13.72
1	120.77	163.10	42.33	58.28	5.81	2.46	2.46	67.98	56.29	41.68
2	150.86	154.37	3.51	41.17	3.67	0.84	1.64	47.32	31.37	30.65
4	107.77	144.82	37.05	52.03	2.62	4.00	2.50	61.15	56.74	42.22

Figure 20. Regression of CEC on Per Cent Loss on Ignition



CEC at pH 7 (meq/100 g)
400
300
200
100
0
0
20
40
60
80
100
LOSS ON IGNITION (LOI)
▲ LEEWARD
○ WINDWARD
CEC = 48.290 + 1.930 (LOI)
r = 0.680 **

Exchangeable Bases, Total Bases, and Base Saturation--Exchangeable bases, total bases, and base saturation are presented in Tables 18, 19, and 20. Calcium appeared to be the dominant base with values ranging from 6.57 to 105.54 meq/100 g. These amounts of calcium are considered high. However, because the amount of water soluble calcium in these soils was found to be low, the majority of it is believed to be in the exchangeable form. Other cations such as magnesium, potassium, and sodium were less than 10 meq/100 g.

Base saturation values at pH 7 ranged from 10 to 50.52 per cent. Base saturation values at pH 4 perhaps is a better estimate of the true base saturation in these soils. The base saturation, calculated by the use of CEC value at pH 4, ranged from 11.8 to 85.2 per cent.

Hawaiian Troposaprists

The data on morphological, chemical, and physical properties of two profiles from the Alakai series are presented in Tables 21, 22, 23, 24, and 25.

Morphological Characteristics

Color--The color varied from horizon to horizon but the differences could not be distinguished by means of the Munsell Color Charts. The color ranged from very dark brown (10YR 2/2) to black (10YR 2/1). The color of the first and second horizons of both profiles were more brown than the third horizon. In general, sample clods were darker or blacker on the outside than the inside, indicating a higher degree of decomposition or humification on the outside. The color of the

TABLE 21. SOME FIELD CHARACTERISTICS OF HAWAIIAN TROPOSAPRIST

Mt. Kaala, Oahu, Hawaii

Sample No.	Depth (cm)	Soil Color	Extract Color (Pyrophosphate)	Remarks
Profile I				
25	0-5	10YR 2/2 10YR 2/1	10YR 6/3	Mostly root mats mixed with partly decomposed material.
26	5-17	10YR 2/2 10YR 2/1	10YR 5/4	More decomposed material than the above.
27	17-32	10YR 2/2 10YR 2/1	10YR 5/4	Highly decomposed materials, though some fiber could be found.
28	32-40	10YR 2/2 10YR 2/1 10YR 4/2	10YR 6/4	Highly decomposed material mixed with mineral soil.
Profile II				
29	0-12	10YR 2/2 10YR 2/1	10YR 6/4	Same as 25.
30	12-27	10YR 2/2 10YR 2/1	10YR 6/4	Same as 26.
31	27-80	10YR 2/2 10YR 2/1	10YR 6/3	Same as 27.
32	80-87	10YR 8/1 10YR 4/2 10YR 2/2 10YR 2/1	10YR 5/4	More mineral soil than 28, and there is a pan at the bottom.

NOTE: R.F. = 2,500 mm, Elevation = 1,220 m, Mapping Unit = r AAE.

third horizon was very black. This was particularly true for the lower boundary of the horizon, indicating it to be in the highest state of decomposition. The color of the fourth horizon was quite different, being composed of a mixture of white (10YR 8/1), dark grayish brown (10YR 4/2), very dark brown (10YR 2/2), and black (10YR 2/1) materials. X-ray diffraction analysis of this horizon revealed the presence of large quantities of gibbsite and moderate to small amounts of anatase, rutile, and magnetite. Van't Woudt and Nelson (1963) found that the mineral horizon of this series on Kauai is composed of kaolin and illite with small quantities of anatase, gibbsite and hydrated illite, most of which appear to be poorly crystallized.

Structure--This soil was found to be always saturated with water. Under such a condition, it is expected to exhibit a massive structure.

Fiber Content--Field determination of fiber content was found to be less reliable than the laboratory method. Large discrepancies existed when the fiber content of a given soil was estimated in the field by different persons. Therefore, the estimates of fiber content reported in Appendix II are not necessarily accurate. Individual judgment is unimportant for the laboratory determination since it is carefully defined by experimental conditions. Those data are shown in a following section.

Boundary--Using criteria similar to those used for mineral soils, namely, color, structure, and root distribution, the boundaries between the organic layers were irregular. However, the boundary between the organic and mineral horizon was abrupt. This might be due to two reasons. One is the presence of a water table and the other is the fact that the organic matter, being less dense than the mineral fraction, tends to float atop the mineral layer. The boundary between the mineral layers was also found to be irregular.

Consistency--The consistency of the organic matter was slightly sticky and slightly plastic as reported earlier for Tropofolists. However, the consistency of the mineral layer was very sticky and very plastic.

Physical Properties

Water Retention--The results of water retention at different tensions are shown in Table 22. The moisture release curves of Profile II are shown in Figure 21.

The water retention is highest in the top layer and decreases with depth. The moisture release curves showed that about one- to two-thirds of the water content was released when the pressure was increased from 1/20 to 1/3 bar. Moisture release curves of the Troposaprists are similar to those of the Tropofolists in that both behaved like a coarse-textured material by releasing large amount of water under low tension, yet behaving like a fine-textured material in retaining much water under high tension. The fourth horizon lost little water under applied tensions reflecting the behavior of a truly heavy textured and nonaggregated material.

The field observations and laboratory data support the findings of Boelter (1969) who stated that water holding capacities of organic soils such as the Troposaprists, depend to a large extent on porosity

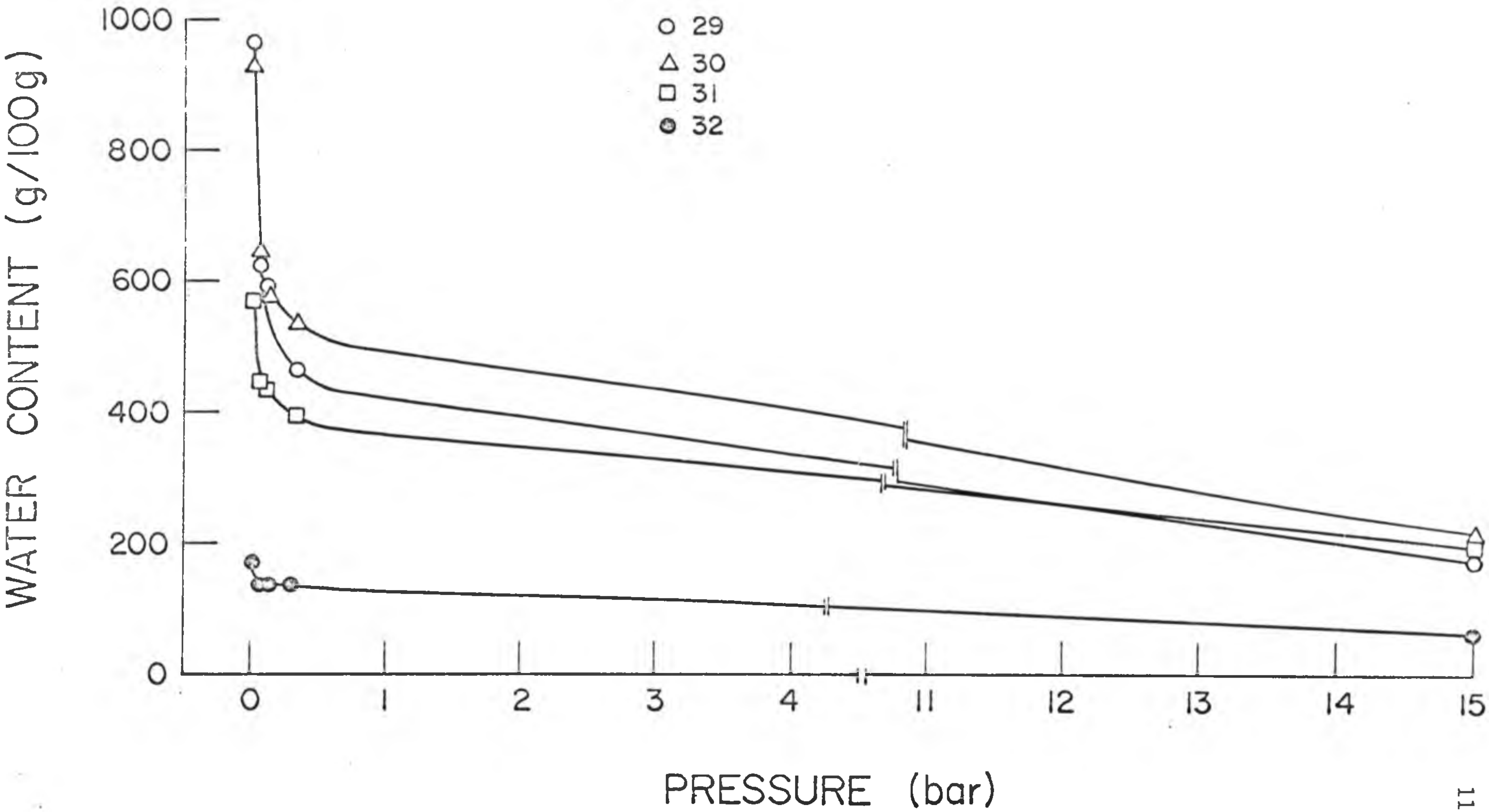
TABLE 22. SOME PHYSICAL PROPERTIES OF HAWAIIAN TROPOSAPRIST

Sample No.	Water Content (%) Saturation	1/20 bar	1/10 bar	1/3 bar	15 bar	Bulk Density (g/cc)	Fiber Content (%)
Profile I							
25	1,010.63	571.58	549.07	359.39	223.56	-	-
26	865.86	489.57	465.17	370.16	178.56	0.10	29.87
27	669.35	373.67	360.98	304.56	215.99	0.14	6.10
28	465.56	334.29	309.25	270.57	150.99	-	-
Profile II							
29	967.13	624.11	569.22	433.62	172.88	-	26.18
30	930.42	647.21	570.65	534.79	212.40	-	14.49
31	570.16	445.45	432.91	398.53	198.40	0.15	3.68
32	171.81	138.35	138.27	138.11	67.32	0.41	-

Figure 21. Moisture Release Curves of Various Horizons from A Hawaiian Troposaprist Profile (Profile II)

<u>Sample No</u>.	
29	Surface horizon (horizon 1)
30	Horizon 2
31	Horizon 3
32	Horizon 4 (mineral horizon)

MOISTURE RELEASE CURVE OF A HAWAIIAN TROPOSAPRIST PROFILE



and pore size distributions. These properties in turn reflect the degree of decomposition. The water retention data of the two profiles showed that large amounts of water were released from the upper portions of the profile suggesting that there is abundance of macropores which are associated with less decomposed materials. On the other hand, smaller amounts of water released from the lower horizons suggest the abundance of micropores which are common in the highly decomposed materials. These indirect conclusions regarding relative degree of decomposition within the profile were supported by direct measurement of fiber content as discussed below.

Bulk Density--The bulk density data of four horizons are presented in Table 22. They varied from 0.10 to 0.41 g/cc. The highest value belongs to the lowest horizon which contains the mineral matter.

Fiber Content--The fiber content ranged from 3.68 to 27.87 per cent on oven-dry weight basis. It is higher at the surface and decreases with depth. For Troposaprists, these results indicate that the fiber content may be a good index of the degree of decomposition, in support of the importance of this criterion as suggested by the Soil Survey Staff (1968).

Chemical Properties

Loss on Ignition (LOI)--Table 23 shows that the upper three horizons of both profiles have higher losses on ignition than the lowest horizons. This is expected because of the higher amounts of combustible organic material in the upper horizons. The LOI values ranged from 42.25 to 97.81 per cent and these were used as estimates of organic matter contents in the samples.

Organic Carbon--Organic carbon, as determined by the Walkley-Black method did not follow the trend of profile distribution obtained by the LOI determination (Table 23). The calculation of organic matter based on a factor of 1.72 (Organic carbon x 1.72) gave values of over 100 per cent for the third horizons of both profiles. As noted earlier for Tropofolists, these results suggest that the factor 1.72 may be too high for Troposaprists as well. A lower factor of 1.50 appears better suited for these two samples.

Total Nitrogen and C/N Ratio--The total nitrogen values (Table 23) ranged from less than 1 per cent in the mineral layer, to 2.5 per cent in the upper horizons. Excluding the mineral layer, these values are generally slightly higher than those reported earlier for Tropofolists. Much of the nitrogen may be complexed with the organic matter and may provide a useful source of mineralizable nitrogen during cultivation under proper environment.

The C/N ratios range from 16 to 69, increasing with depth going down profile except for the second horizon of Profile I. It is generally acknowledged that a wide C/N ratio is associated with the slow decomposition of organic matter. Obviously under such submerged conditions, the lower horizons exhibited less carbon loss, as CO_2, than did the upper horizons (Alexander, 1961).

Absorbance and Degree of Decomposition--Absorbances of pyrophosphate extracts of Troposaprists were shown to be related to the degree of decomposition of organic matter. Both profiles showed high amounts of organic matter with the exception of the fourth horizon of

TABLE 23. CHEMICAL PROPERTIES OF HAWAIIAN TROPOSAPRISTS

Sample No.	LOI[a] (%)	Org. C. (%)	LOI / Org. C.	OM[b] (%)	Total N (%)	C/N	Absorbance	Degree of Decomposition[c]
Profile I								
25	93.60	53.90	1.736	92.71	2.28	24	84	90 (L)
26	93.21	41.12	2.266	70.73	2.54	16	206	221 (M)
27	93.10	66.02	1.410	114.55	1.83	36	378	406 (H)
28	84.28	52.45	1.607	90.21	0.71	69	741	879 (H)
Profile II								
29	96.40	49.59	1.944	85.29	2.92	17	109	113 (L)
30	96.82	54.61	1.773	93.93	2.04	27	216	223 (M)
31	97.81	61.39	1.593	105.59	1.14	54	633	647 (H)
32	42.25	24.13	1.751	39.50	0.22	27	270	639 (H)

[a]LOI = Loss on ignition

[b]OM = Organic matter (Org. C x 1.72)

[c]Relative degree of decomposition expressed as low (L), medium (M) or high (H) according to absorbance of pyrophosphate extracts adjusted to correct for organic matter content in the samples.

Profile II. Calculation of absorbance and the degree of decomposition based on the organic matter content showed that absorbance and consequently the degree of decomposition, increases with depth. In the fourth horizons of both profiles, due to the presence of appreciable amounts of mineral matter, the organic matter content is lower than in the upper horizons. However, when absorbance values are adjusted according to the organic matter content, it is clear that organic matter in all horizons, including the two mineral horizons, is in the highest state of decomposition.

Humic Acid (H), Fulvic Acid (F) and H/F Ratio--The results of the two profiles appear to follow the trends observed by Kosaka (1963), namely, that the humic acid content and H/F ratio should increase by increasing degree of decomposition. However, the H/F ratios follow a trend different from that reported by Rode (1962). They, nevertheless, are in accordance with the findings of several other authors who showed that the degree of decomposition increased with depth in profile. Fulvic acid appears to decrease within a soil profile increasing depth, except for the fourth horizon of Profile I. However, it may not be correct to conclude that fulvic acid decreases with decreasing degree of decomposition because fulvic acid does not precipitate even when the pH is slightly below 2.

pH--The pH values of these samples are considered extremely acid according to the criteria used by the Soil Survey Staff (1951). The values range from 3.32 to 3.67 with an average of 3.50. The delta pH values for all horizons are negative.

The influence of organic acids on the underlying rock is evidenced by the presence of a white layer in the fourth horizon, which has the morphological and bleached appearance of the "albic" horizon. The effects of these acids are further reflected in the underlying horizon which resembles the "spodic" horizon in a Spodosol which shows the accumulation of iron oxides (Figure 5A).

Cation Exchange Capacity, Exchangeable Bases, and Base Saturation--As in the case of Tropofolists, the CEC values reflected pH dependence as they increased when the pH of the extracting agent was raised from 4 to 7. The value ranged from 89.49 to 314.44 meq/100 g at pH 4 and from 115.95 to 424.98 meq/100 g at pH 7. The values appeared to be higher than those obtained by other investigators. However, the values could not be compared due to the difference among the methods used.

The high amounts of extractable bases, especially calcium, in the surface horizon may be due to recycling by natural vegetation. Compared to most highly weathered inorganic soils, the total bases are relatively low. However, for similar organic soils, these values are relatively high. Such high values may have been obtained because the calculation of extractable bases was carried out on oven-dry basis.

TABLE 24. CHEMICAL PROPERTIES OF HAWAIIAN TROPOSAPRIST (Cont.)

Sample No.	Humic Acid (H) (%)	Fulvic Acid (F) (%)	H/F	pH (1:1) H_2O	pH (1:1) KCl	ln 0.01 M $CaCl_2$	Delta pH $pH_{KCl} - pH_{H_2O}$
Profile I							
25	19.50	11.08	1.55	3.50	2.97	3.02	-0.48
26	20.05	8.69	2.74	3.55	2.88	3.11	-0.67
27	35.69	7.54	6.30	3.49	2.78	3.04	-0.51
28	39.58	11.64	6.28	3.49	2.68	2.88	-0.81
Profile II							
29	26.25	16.50	1.36	3.14	2.55	2.70	-0.59
30	41.90	7.42	9.67	3.32	2.60	2.76	-0.72
31	42.76	4.30	9.94	3.38	3.18	3.08	-0.20
32	13.44	1.90	7.10	3.67	3.59	3.59	-0.08

TABLE 25. CHEMICAL PROPERTIES OF HAWAIIAN TROPOSAPRIST (Cont.)

Sample No.	CEC (meq/100 g) pH 4	CEC (meq/100 g) pH 7	Delta CEC pH 7 - pH 4	Exch. Bases (meq/100 g) Ca	Exch. Bases Mg	Exch. Bases K	Exch. Bases Na	Total Bases	BS pH 4 (%)	BS pH 7 (%)
Profile I										
25	205.43	394.37	189.94	20.27	5.24	4.56	2.63	32.70	15.92	8.29
26	197.22	393.57	196.35	8.98	5.05	1.23	0.66	15.19	8.07	4.14
27	206.05	381.64	175.59	8.91	4.65	0.20	0.50	14.26	6.92	3.63
28	317.63	341.77	24.04	2.50	2.61	2.17	1.80	9.14	2.88	1.70
Profile II										
29	314.44	345.59	11.15	5.04	5.01	2.17	1.86	14.08	4.48	4.07
30	187.12	357.86	170.74	5.17	1.17	0.35	1.03	7.72	4.12	2.11
31	-	424.98	-	1.62	3.29	0.48	0.57	5.96	-	1.40
32	89.49	115.95	26.46	0.47	0.10	0.11	0.07	0.75	0.84	0.64

SUMMARY AND CONCLUSION

The objectives of this investigation were:

1. To examine some of the factors of formation of Hawaiian Histosols.

2. To investigate the nature, properties, and potential uses of Hawaiian Histosols.

3. To test the parameter recommended for the classification of Histosols.

4. To examine the definition of organic horizons (the Histic Epipedons) of Hawaiian Histosols.

Many of the criteria used for classifying organic soils were proposed by the Soil Survey Staff (1968 and 1969) and other workers. Procedures for this study were chosen on the basis of being simple and practical and lying within the limitations of existing facilities. Soil color, structure, consistency, fiber content (field), and the color of saturated sodium pyrophosphate extract were the morphological properties used in this study. Moisture retention characteristics of these soils were determined at several tensions. Fiber content determined in the laboratory as suggested by the Soil Survey Staff (1968), was not found to be a reliable parameter for characterizing the Tropofolists. However, it was found to be more reliable when characterizing the Hawaiian Troposaprists. Determinations of bulk density by the clod method could not be used for many of the Tropofolists. The absorbance readings of dilute sodium pyrophosphate extract of these soils were influenced by the amount of organic matter and could not be used to get a direct measure of the degree of decomposition. A highly reliable index was obtained, however, when the values were adjusted according to the organic matter content. Loss on ignition was used as an estimate of the organic matter content in both the Tropofolists and Troposaprists.

The pH of the samples was measured in 1:1 systems of water, KCl and in 0.01 M $CaCl_2$. Cation exchange capacities were obtained by the ammonium acetate method at pH values of 4 and 7. Based on the results obtained by using these and other criteria, the following conclusions were made.

Hawaiian Tropofolists

These soils contain more than 15 per cent organic matter and occur at the elevation from near sea level to just below the timber line. The samples were selected from locations where mean annual rainfall ranged from 75 to 550 cm. Although Tropofolists are presumed to occur under temperatures ranging from 8^oC (47^oF) to more than 22^oC (72^oF), the sites from which samples were collected had temperatures ranging between 15^oC (59^oF) to 23^oC (73^oF).

Tropofolists were found to be shallow organic soils which exist on fresh aa or pahoehoe lava rocks. Factors which affect vegetation such as climate, rainfall, and underlying types of lava rocks directly affect the formation of these soils. The soils are stable only as long as natural vegetation is present. Such vegetation provides sufficient supplies of organic materials to offset the high rate of decomposition. Shading by large trees also reduces decomposition rates.

Soil colors generally ranged from very dark brown to black. They appeared to be highly decomposed, as indicated by field observation and laboratory measurements using color tests with sodium pyrophosphate solutions. The fibers appeared to be primarily fine roots and portions of decomposing tree trunks. Often, the organic soil materials were mixed with fine to coarse sized fragments of rocks, volcanic glass or minerals such as olivine. Some pieces of charcoal were often found in the leeward samples, indicating the possibility that forest fires may have occurred sometime ago. No clay minerals were detected by X-ray diffraction analysis which showed only rock forming minerals such as feldspars and amorphous organic soil materials.

The moisture characteristics of these Tropofolists were found to be different from those generally known for mineral soils. This is because organic soil components have higher water holding capacities. The samples stored large amounts of water at saturation and released large amounts when small tensions, such as 1/20 bar (50 cm), were applied. Notably, these organic soils also retained relatively large percentages of water at 15 bars tension when compared to mineral soils. Soil bulk densities could not be determined, but in a few samples, they were generally low as long as no rock fragments were mixed in the samples.

Humic acid contents in these Tropofolits, as measured in the acid precipitates of 0.5 N NaOH extracts, were positively correlated (r=0.552**) with the absorbances of their respective pyrophosphate extracts. This relationship indicated, in agreement with published literature, that the production of humic acid increased with increasing degree of decomposition. The Tropofolists generally exhibited a pH value of about 5. As expected, the CEC values of Tropofolists were relatively high. However, the base saturation values were generally higher than expected even when based on CEC values at pH 4. Therefore, the fertility status of the Hawaiian Tropofolists are not low.

The Soil Conservation Service, USDA, recommends that Hawaiian Tropofolists be grouped into 14 series. This recommendation takes into account elevation, climate, and crop adaptation. However, from laboratory characterization, only minor distinctions were observed among the 9 series collected. It is not possible, therefore, to provide analytical bases for the proposed SCS Classification.

Hawaiian Troposaprists

Only one series of this great group, the Alakai series, exists in Hawaii. This series was formerly known as a bog soil and is always saturated with water. High moisture due to fog drips and clouds added to annual rainfall, cool climate, and poor drainage are the characteristic factors which lead to the formation of the soil. Extreme acidity of the soil results from these formation patterns. The Alakai series was found to contain more than 90 per cent of organic matter. The sample occurs on Oahu in an area receiving 250 cm of annual rainfall and at an elevation of 1212 cm with mean annual temperature of $15^{o}C$ ($59^{o}F$). This organic layer was underlain by a mineral profile which is well-developed into two horizons and which resembles morphologically the albic and spodic horizons of Spodosols. The horizon just below the organic horizon contains predominantly gibbsite and oxides of titanium and iron. The color of the organic horizon varies from very dark brown to black. The underlying horizon is composed of a mixture of white, gray, very dark brown, and black materials.

The moisture characteristics of the organic horizon were found to be similar to those of the Tropofolists. However, the characteristics of the mineral layer were similar to those of fine-textured or clayey soils. The bulk density values were generally low and increased with depth within the profile as did the humic acid contents. This indicated a positive correlation between humic acid content and degree of decomposition, a trend which is similar to that in the Tropofolists.

Measured pH values were considerably lower than those of the Tropofolists. This may be due to the fact that organic matter in the Troposaprists, being always under submerged conditions, undergoes much partial decomposition giving rise to many organic acids or similar derivatives. Further explanation may lie in the fact that recycling of bases by growing plants is always more effective in shallow soils, or surface layers of deep soils, thus the high pH values in Tropofolists.

Although the CEC was very high, the base saturation was relatively low, indicating a lower fertility status in the Tropofolists. In view of results obtained on these Troposaprists profiles, it is proposed that they be called "Clayey, gibbsitic, dysic, isomesic, Terric Troposaprists" rather than "Clayey, kaolinitic, dysic, isomesic, Terric

Troposaprists" as proposed by SCS.

Histic Epipedons of Hawaiian Histosols

According to the Soil Survey Staff (1968) the Histic Epipedons were defined by using three key properties which are organic matter content, moisture pattern, and depth of the organic layer.

Based on the results reported in the study, the Histic Epipedons of Hawaiian Histosols appear to be of two types which are different in those key properties. The first is shallow and is not always saturated with water. Generally, it has an organic content of more than 15 per cent but can range from 10 to 90 per cent depending on soil depth. The depth of this kind of histic epipedon ranges from less than 2.5 cm to 40 cm to the lithic substratum. Organic soils in which this epipedon exists are classified as the Tropofolists. The second type of histic epipedons is always saturated with water. The organic content is always very high and the horizon may be considered to be purely organic. The depth of the profile studied is about 87.5 cm, the minimum depth of this series, and the horizon underlain by a mineral horizon which also has a high organic content. Organic soils in which this type of histic epipedon is encountered are classified as Troposaprists.

Comments Regarding the Potential Use of Tropofolists

Tropofolists occupy about 40 per cent of the area of the island of Hawaii, or 412,672 hectares which is about 25 per cent of the area of the State of Hawaii. At present, the use of Tropofolists for agriculture is still very limited, despite the relatively large area. Present uses include the growing of coffee, macadamia nut, papaya, citrus, sugarcane, guava, pasture, and forest trees for timber production. Some Tropofolist lands are preserved as a national park. The crops appear to give good yields which may encourage further expansion in the use of these lands. Pasture also appears to be a good use of these soils. Many kinds of grasses adapt very well on these soils and under these climates. Among the grasses found at the sample sites and which could be considered for pasture production are Hilo grass, carpet grass, kikuyu, puu lehua, para grass and others. Timber production could be of economic importance because certain trees from the temperate zone could be grown on Tropofolists at high elevation.

One obvious advantage in using these Tropofolists is that there appears to be no need for irrigation in most places if the chosen crops can survive in shallow soils. From the results of this investigation the fertility status of Tropofolists is relatively high. However, there is an obvious need to study fertility requirements of these Tropofolists in more detail. Even though organic matter may disappear rapidly after forest clearing, it may be that some such material remain in the rock crevices and behave as a medium in storing water and nutrients. Management of these soils is unique and differs from other organic soils in that drainage is not an important problem. In crop production some farmers apply about 10 cm thickness of sugarcane bagasse on the rock surface to make up for the organic matter lost by oxidation.

Since organic matter is generally expected to decompose very rapidly from these soils, it may not be practical to use high amounts of artificial fertilizers at one application for certain reasons. First, nutrients applied may help increase the activities of organisms that are responsible for oxidation and increase the rate of oxidation of organic matter. Second, when organic matter is lost, the nutrients might be subjected to severe losses by leaching in such a wet region. Therefore, it might be necessary to apply fertilizers frequently and lightly. Finally, it must be recalled that large shrinkage and high oxidation occur due to loss after exposing the soils from native vegetation. Therefore, planting should be started as soon as the forest is cleared or avoid large losses of the organic matter by blowing or rapid oxidation.

Comments Regarding the Potential Use of Troposaprists

Literature surveys showed that there are extensive areas of bog soil formations in the tropics which contain either high or low lime contents. These soils are used in agriculture if their geographical locations allow such practices. The soils that are not geographically within the convenient reach of people were usually left unused. In Hawaii, this is the case of the Alakai series which serves its best use as a watershed area. Other factors dictating this use may be:

1. They mostly occur under such excessive rainfall that would not allow most plants to develop well. This climatic factor is not subject to change except indirectly by correcting excessive soil moisture by means of expensive drainage installations.

2. Excessive acidity conditions make it uneconomical to reclaim this land.

3. The area of these soils is not sufficiently large to warrant economic use for agricultural production.

Comments on the Criteria of the Present Histosol Classification

Based on the data obtained during the course of this study, certain comments may be made in the various criteria:

1. The use of the terms "euic" and "dysic." Generally, the pH values for the same soil series are not always constant as they vary within a certain range depending on many factors. Using arbitrary pH values below or above 5.5, to classify Tropofolist soil at the family level may be misleading when soil correlation is to be made. The average pH obtained for Tropofolists samples in 0.01 M $CaCl_2$ is 5 and pH values for individual samples ranged from slightly less than 4 to slightly more than 6. Often, the pH value for the same soil series was above or below 5.5. For this reason it may be better not to use such arbitrary pH levels for classification terminology. Nevertheless, such terminology as euic and dysic may be of more value in other types of organic soils.

2. Classification at the series level. The Tropofolists, samples under study, generally had similar characteristics. However, they occur under a wide range of climatic conditions. It appears reasonable to separate them into series according to these climatic and forming

factors. In doing so, the interpretation of the soils becomes feasible for use in elevation and crop adaptation. This is true since certain plant species may be able to survive on these shallow soils under certain climatic conditions but may not survive on the same type of soil under a different set of climatic conditions. The Troposaprists of Hawaii at present all belong to one series (Soil Conservation Service, USDA). However, the mineralogy of the underlying mineral layers of these soils is clearly different when the result of this study is compared with those of Van't Woudt and Nelson (1963). In addition, the amount of rainfall is significantly different among these soils. It may well be worthwhile to separate these soils into various categories at the family level. Since these soils appear to be best suited for watershed areas and their acreage is so small compared to the Tropofolists, such separation does not seem necessary.

LITERATURE CITED

Alexander, M. 1961. Introduction to soil microbiology. John-Wiley and Sons, Inc., New York and London.

Atkinson, I. A. E. 1969. Rate of ecosystem development on some Hawaiian lava flows. Unpublished Ph.D. Dissertation. Univ. of Hawaii. 197 pp.

Auer, V. 1933. In "Handbuch der Moorkunde" (K. V. Bulow, ed.). Vol. 7:141-223. Gebruder Borntraeger, Berlin.

Ayres, A. S. 1943. Soils of high-rainfall areas in the Hawaiian islands. Hawaii Sgr. Expt. Sta. Tech. Bull. 1.

Bailey, H. H. 1950. Peat formation in the tropics and subtropics. Soil Sci. Soc. Am. Proc. 14:283-284.

Barber, S. A. P. et al. 1965. Isolation and preliminary characterization of soil polysaccharrides. Nature. 205:68-69.

Black, C. A. (ed.) 1965. Method of soil analysis. Parts I and II. Agronomy No. 9. ASA, Madison.

Blake, G. R. 1965. Bulk density. In Black, C. A. (ed.) Method of soil analysis. Part I, Chapt. 30. Agronomy No. 9. ASA, Madison.

Blumenstock, D. I. and S. Price. 1967. Climates of the States. Hawaii. Climatography of the United States. No. 60-51. U. S. Dept. of Commerce, Washington, D. C.

Boelter, D. H. and ~~G. R. Blake.~~ 1964. Importance of volumetric expression of water contents of organic soils. Soil Sci. Soc. Am. Proc. 28:176-178.

__________. 1964. Water storage characteristics of several peats in situ. Soil Sci. Soc. Am. Proc. 28:433-445.

__________. 1969. Physical properties of peats as related to degree of decomposition. Soil Sci. Soc. Am. Proc. 33:606-609.

Bremner, J. M. 1965. Total nitrogen. In Black, C. A. (ed.) Methods of soil analysis. Part II. Agronomy No. 9.

Broadbent, F. E. and G. R. Bradford. 1952. Cation exchange in organic fraction. Soil Sci. 74:447-457.

__________. 1953. The soil organic fraction. Advances in Agronomy. 5:153-158.

Broadbent, F. E. 1965. Organic matter. In Black, C. A. (ed.) Method of soil analysis. Agronomy No. 9:1397-1408.

Buckman, H. O. and G. R. Brady. 1969. The nature and properties of soils. The Macmillan Company, N. Y.

Burge, W. D. and F. E. Broadbent. 1961. Fixation of ammonia by organic soils. Soil Sci. Soc. Am. Proc. 25:199-204.

Cline, M. G. et al. 1955. Soil survey. Territory of Hawaii. U.S.D.A. Soil Survey Series No. 25.

Coleman, N. T. and G. T. Thomas. 1967. The basic chemistry of soil acidity. In Pearson, R. W. and F. Adams. Soil acidity and liming. Am. Soc. Agron. Mono. No. 12.

Cook, R. L. 1962. Soil management. For conservation and production. John-Wiley and Sons, Inc., N. Y.

Crosby, W. and E. Y. Hosaka. 1955. Vegetation. In Cline, M. G. et al. (1955). Soil Survey Territory of Hawaii.

Cunningham, R. K. 1963. The effect of clearing a tropical forest soils. J. Soil Sci. 14:334-345.

Dachnowski-Stoke, A. P. 1933. Peat deposits in the United States of America. Handbuch der Moorkunde. Edited by K. V. Bulow. Vol. 7:1-140. Berlin: Gebruder Bortraeger.

Dawson, J. E. 1956. Organic soils. In Adv. in Agronomy 8:377-402.

DeBano, L. F., L. D. Mannand and D. A. Hamilton. 1970. Translocation of hydrophobic substances into soil by burning organic litter. Soil Sci. Soc. Am. Proc. 130-133.

Degener, O. 1945. Plants of Hawaii National Park. Illustration of plants and customs of the south seas.

__________. 1964. Flora Hawaiiensis or new illustrated flora of the Hawaiian Islands.

Dolman, J. D. and S. W. Buol. 1968. Organic soils on the lower Coast Plain of North Carolina. Soil Sci. Soc. Am. Proc. 32:414-418.

__________. 1968. Genesis, morphology and classification of organic soils in the tidewater region of North Carolina. Ph.D. Dissertation. Univ. of North Carolina.

Doty, M. S. and D. Mueller-Dombois. 1966. Atlas for biology studies in Hawaii Volcano National Park. Univ. of Hawaii. Hawaii Botanical Science Paper No. 2.

Dual, R. S. and F. R. Moorman. 1964. Major soils of Southeast Asia and their characteristics, distribution, use, and agricultural potential. J. Tropical Geography. Vol. 28.

Dubach, P. and N. C. Mehta. 1963. The chemistry of soil humic substances. Soils and Fertilizer 26 (5):293-300.

Farnham, R. S. and H. R. Finney. 1965. Classification and properties of organic soils. Adv. in Agronomy. 27:115-162.

Felback, Jr. G. T. 1965. Study on the high pressure hydrogenalysis of organic matter from muck soils. Soil Sci. Soc. Am. Proc. 29:48-55.

Feustel, I. C. and H. G. Byers. 1930. The physical and chemical characteristics of certain American peat profiles. U.S.D.A. Technical Bull. No. 214:1-26.

Forbes, C. N. 1912. Preliminary observations concerning plant invasion on some of the lava flows of Mauna Loa, Hawaii. Bernice P. Bishop Mus. Occ. Papers 5 (1):15-23.

Frazer, G. D. 1960. Pahala Ash--An unusual deposit from Kilauea Volcano, Hawaii. U. S.Geological Survey Prof. paper. 400:B-354-5.

Gorham, E. 1957. The development of peatland. Quart. Rev. Biol. 32:145-166.

Greenland, D. J. 1965. Interaction between clays and organic compounds in soils. Part II. Absorption of soil organic compounds and its effect on soil properties. Soils and Fertilizers 28 (6):521-532.

Hanrahan, E. T. 1954. An investigation of some properties of peat. Geotechnique 4:108-123.

Harris, C. I. and G. F. Warren. 1962. Determination of phosphorus fixation capacity in organic soils. Soil Sci. Soc. Am. Proc. 26:381-383.

Heinselman, M. L. 1963. Forest sites, bog processes and peatland type in glacial lake Agassiz Region, Minnesota. Ecol. Mono. 33:327-374.

Heintze, S. G. and P. J. G. Mann. 1951. A study of various fractions of manganese of neutral and alkaline organic soils. J. Soil Sci. 2:234-242.

Hock, T. T. 1968. A short review of peat in Malaya and Sarawak. Unpublished report. Pineapple Research Station. Pekan Nenas, Malaysia.

Hubbard, D. H. 1952. Ferns of Hawaii National Park. Hawaii Nature Notes. Nationalist Division, Hawaii National Park and Hawaii Natural History Assoc.

Isirimah, N. O., D. R. Keeney and G. B. Lee. 1970. Chemical differentiation of Wisconsin Histosols. Soil Sci. Soc. Am. Proc. 34:478-482.

Jenkins, D. A. and R. I. Davies. 1966. Trace element content of organic accumulation. Nature. 210:1296-1297.

Jenny, H. 1958. Role of plant factor in pedogenic function. Ecology 39:5-16.

Jongedyk, H. A., R. B. Hickok, I. D. Mayer, and N. K. Ellis. 1950. Subsidence of muck soils in northern Indiana. Purdue Univ. Agr. Expt. Sta., Lafayette, Indiana C66:3-11.

__________, __________, and __________. 1954. Changes in drainage properties of a muck soil as a result of drainage practice. Soil Sci. Soc. Am. Proc. 18:72-76.

Kaila, A. 1960. Determination of degree of humification in peat samples. Maataloust Aikak. 28(1):18-30.

Kanehiro, Y. and G. D. Sherman. 1956. Effect of dehydration-rehydration on CEC of Hawaiian soils. Soil Sci. Soc. Am. Proc. 20:341-344.

de Kock, P. D. 1955. Influence of humic acids on plant gorwth. Science 121:473-474.

Kononova, M. M. 1965. Soil organic matter. 2nd. ed. Pergamon Press, Oxford.

Kosaka, J. 1963. Division of process of humification in upland soils, and its application to soil classification. Soil Sci. and Plant Nutrition. 9:14-18.

__________, C. Honda, and A. Izaki. 1962. Formation of humus in upland soils. Soil Sci. and Plant Nutrition. 8(6):234-239.

Krajina, V. J. 1963. Biogeoclimatic zones on the Hawaiian Islands. Newsletter of the Hawaiian Botanical Society 2(7):93-98.

Kubiena, W. L. 1953. The soils of Europe. Thomas Murray and Company, London.

Kuntze, H. 1965. Physikalische Unteruchungs-methoden für Moor und Anmoorboden (English summary) Landwirtschaftliche Forschung 18:178-191.

Larson, J. E. et al. 1958. Study on leaching of applied labelled phosphorus in organic soils. Soil Sci. Soc. Am. Proc. 22:558-560.

Lucas, R. E. and J. F. Davis. 1961. Relationships between pH values of organic soils and availabilities of 12 plant nutrients. Soil Sci. 92:177-182.

Mackenzie, A. F. and J. E. Dawson. 1962. A study of organic horizons using electrophoretic techniques. J. Soil Sci. 13 (2):160-166.

MacLean, A. J. et al. 1964. Comparison of procedure for estimating exchange properties and phosphorus and potassium in some eastern Canadian organic soils. Canadian J. Soil Sci. 44:66-75.

McCaughey, V. 1917. Vegetation of Hawaiian lava flows. Botanical Gazette 64:386-420.

McKeague, J. A. 1968. Humic-fulvic acid ratio, Al, Fe, and C in pyrophosphate extracts as criteria of A and B horizons. Canadian J. Soil Sci. 48:27-35.

Mirza, C. and R. W. Irwin. 1964. Determination of subsidence of an organic soil in Southern Ontario. Canadian J. Soil Sci. 44:248-253.

Moir, W. W. G. et al. 1935. Handbook of Hawaiian soils. Assoc. of Hawaiian Sugar Technologist, Honolulu.

Mueller-Dombois, D. 1966. The vegetation map and vegetation profile. In Doty, M. S. and D. Mueller-Dombois. Atlas for bioecology studies in Hawaii Volcano National Park. Hawaii Bot. Sci. Paper 2:391-441.

__________ and V. J. Krajina. 1968. Comparison of east-flank vegetations on Mauna Loa and Mauna Kea, Hawaii. Proc. Sym. Recent Adv. Trop. Ecol. 508-519.

__________ and C. H. Lamoureux. 1967. Soil-vegetation relationships in Hawaiian Kipukas. Pacific Science 21:286-299.

Naylor, D. V. and R. Overstreet. 1969. Sodium-calcium behavior in organic soils. Soil Sci. Soc. Am. Proc. 33:848-851.

Nygard, I. J. 1954. Identification of lime-deficient peat soils. Soil Sci. Soc. Am. Proc. 18:188-193.

Olenin, A. S. 1963. Peat resources of the USSR. In Second International Peat Congress. Vol. I:1-14.

Powers, H. A., J. C. Ripperton and Y. B. Goto. 1932. Survey of the physical features that affect the agriculture of Kona District of Hawaii. Hawaii Agr. Expt. Sta. Bull. No. 66. 29 pp.

Robyns, W. and S. H. Lamb. 1939. Preliminary ecological survey of the island of Hawaii. Bull. Jord. Bpt. Brux. 15:241-293.

Rode, A. A. 1962. Soil science. Published for the National Science Foundation, Washington, D. C.

Russell, E. W. 1966. Soil conditions and plant growth. Longmans, Green and Co., Ltd., London.

Scheffer, F. and B. Ulrich. 1960. Humus and humusdüngung. Enke, Stutgart.

Schnitzer, M. and J. G. Desjardins. 1965. Carboxyl and phenolic hydroxyl groups in some organic soils and their relation to the degree of humification. Canadian J. Soil Sci. 45:157-164.

__________ and U. C. Gupta. 1965. Determination of acidity in soil organic matter. Soil Sci. Soc. Am. Proc. 19:274-277.

__________ and I. Hoffman. 1966. A thermogravimetric approach to the classification of organic soils. Soil Sci. Am. Proc. 30:63-66.

Sheridan, E. T. and V. C. Berte. Peat. Mineral Yearbook. Vol. 2:279-295.

Sherman, G. D. and Y. Kanehiro. 1948. The chemical composition of certain forest floors in the Hawaiian Islands. Biennial Reports. University of Hawaii. Agr. Expt. Sta. Honolulu. p. 54.

Skottsberg, C. 1941. Plant succession on recent lava flows in the island of Hawaii. Gotteborgs Kungl Vetenskapoch Vitterhetssam-halles. Handlinger Sjatte fojen, ser. B., Bd. 1, No. 8:32 pp.

Soil Survey Staff. 1951. Soil Survey Manual. U.S.D.A. Handbook No. 18.

__________. 1960. Soil Classification. A comprehensive system. 7th Approximation. U.S.D.A.

Soil Survey Staff. 1967. Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Investigations Report No. 1. Soil Conservation Service, U.S.D.A.

__________. 1968. Supplement to classification system. 7th Approximation. Histosols. U.S.D.A.

__________. 1969. Soil classification Folists.

Stearns, H. T. 1966. Geology of the State of Hawaii. Pacific Books. Palo Alto, California.

__________ and G. A. Macdonald. 1946. Geology and ground-water resources of the island of Hawaii. Bull. 9. Hawaii Division of Hydrography.

__________ and K. N. Vaksvik. 1935. Geology and ground-water resources of the island of Oahu, Hawaii. Division of Hydrography. Bull. No. 1. U. S. Geological Survey.

Swain, F. M. 1963. Geochemistry of humus. In Organic Geochemistry. I. A. Breger (ed). International Series of Monographs on Earth Science. Pergamon Press Book. The Macmillan Company, N.Y.

The Terminology Committee of Soil Sci. Soc. Am. Proc. 1965. Glossary of Soil Science Terms. 29:330-351.

Tisdall, A. L. 1951. Comparison of methods of determining apparent density of soils. Australian J. Agr. Res. 2:349-354.

Townsend, L. R. and D. C. Mackay. 1963. The effect of cropping on some chemical properties of a sphagnum peat soil. Canadian J. Soil Sci. 43:171-177.

U.S.D.A. 1968. Soil legend: island of Hawaii, Hawaii. Unpublished. 7 pp.

Vageler, P. 1933. An introduction to tropical soils (Translation by H. Green). Macmillan and Co., Ltd., London.

Van't Woudt, B. D. and R. E. Nelson. 1963. Hydrology of the Alakai Swamp. Kauai, Hawaii. Hawaii Agr. Expt. Sta. Bull. No. 32.

Visser, S. A. 1962. Production of humic substances in decomposing peat and compost samples. Nature 196:1211-1212.

__________. 1964. Oxidation-reduction potential and capillary activities of humic acids. Nature 198:581.

Waksman, S. A. 1942. The peat of New Jersey and their utilization. Part A. Dept. of Conservation and Development, State of New Jersey, 20.

Weir, W. W. 1950. Subsidence of peatlands of Sacramento-San Joaquin Delta, California. Hilgardia 20:37-56.

APPENDIX I

SOIL LEGEND

rKAD	Kahaluu extremely rocky muck, 6 to 20 per cent slopes
rKED	Kaimu extremely stony peat, 6 to 20 per cent slopes
rKFD	Keaukaha extremely rocky muck, 6 to 20 per cent slopes
rKGD	Keei extremely rocky muck, 6 to 20 per cent slopes
rKHD	Kekaha extremely rocky muck, 6 to 20 per cent slopes
rKXD	Kiloa extremely rocky muck, 6 to 20 per cent slopes
rKYD	Kona extremely rocky muck, 6 to 20 per cent slopes
rLLD	Lalaau extremely stony muck, 6 to 20 per cent slopes
rLV	Lava flow, Aa
rLW	Lava flow, Pahoehoe
rMWD	Mawae extremely stony muck, 6 to 20 per cent slopes
rPAE	Papai extremely stony muck, 3 to 25 per cent slopes
rPXE	Puna extremely stony muck, 3 to 25 per cent slopes
rPYD	Punaluu extremely rocky peat, 6 to 20 per cent slopes
HCD	Hanipoe very stony loam, 12 to 20 per cent slopes
HDD	Hanipoe silt loam, 12 to 20 per cent slopes
HFD	Hanipoe very rocky silt loam, 6 to 20 per cent slopes
HND	Honaunau silt loam, 6 to 20 per cent slopes
HRD	Honaunau extremely rocky silty clay loam, 6 to 20 per cent slopes
HUD	Honuaulu very stony silty clay loam, 12 to 20 per cent slopes
HVD	Honuaulu extremely stony silty clay loam, 12 to 20 per cent slopes

KDD	Kainaliu very stony silty clay loam, 12 to 20 per cent slopes
KEC	Kainaliu extremely stony silty clay loam, 12 to 20 per cent slopes
KPD	Kealakekua silty clay loam, 12 to 20 per cent slopes
KRD	Kealakekua very stony silty clay loam, 6 to 20 per cent slopes
KSD	Kealakekua extremely stony silt loam, 12 to 20 per cent slopes
MMD	Manahaa silt loam, 6 to 20 per cent slopes
MND	Manahaa extremely stony silt loam, 6 to 20 per cent slopes
WHC	Waiaha extremely stony silt loam, 6 to 12 per cent slopes

APPENDIX II

DESCRIPTIONS OF THE SOILS

Some of the soil descriptions were made in the field. However, many of the descriptions were prepared in the laboratory. In making these descriptions, the recommendations of the Soil Survey Staff (1951 and 1968) were followed. The location, parent rock, vegetation and elevation of the samples were determined.

In providing the vegetation information, both the natural and introduced types were taken into account. Soil color was determined in the natural and other conditions. The term wet used in some color designations refers to the color obtained when water was added to the sample. The terms pressed and rubbed refer to the colors obtained for the moist soil after being subjected to both pressing and rubbing by hand, both of which may cause significant color changes in organic soils. The methods to determine the colors in saturated pyrophosphate, fiber contents, soil structures, consistencies, and soil reactions are described under the section, "Materials and Methods." Whenever possible, relatively fresh materials which provided the origin for organic soil formations were described. Objects such as rock and charcoal fragments were also described because they may have significance in the formation of these soils.

The Kealakekua Sequence

Samples of this sequence and the Kainaliu sequence were collected by H. Ikawa, H. H. Sato, R. Oldeman, and N. Yaibuathes. Plants from the sample sites were identified by K. Kartawinata. Samples were collected on December 27 and 28, 1969.

Site 5 — Sample 5 was collected at the timberline. Only lichens and *Metrosideros* were dominant species at that high elevation.

Location: Bishop Estate Land in Kona, Island of Hawaii. (Map on Fig. 12)

Parent rock: Aa lava.

Vegetation:
Ohia lehua (*Metrosideros polymorpha*)
Tree fern (*Cibotium glaucum*)
Moss
Lichens
Yellow foxtail (*Setaria geniculata*)
Thimble berry (*Rubus rosaefolius*)
Carpet grass (*Axonopus affinis*)
Kukainene (*Coprosma ernodeoides*)
Kikuyu (*Pennisetum clandestinum*)
Moa (*Psilotium nudum*)
Pukeawe (*Styphelia tameiameiae*)

Elevation: 1,303 m.

Note: Grab sample, under an ohia lehua.

Depth
0-5 cm — Mixed dark reddish brown (5YR 3/2) and dark yellowish brown (10YR 3/4), black (10YR 2/1) wet, very dark brown (10YR 2/2) pressed, very dark brown (10YR 2/2) rubbed, yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly roots); weak to structureless, fine to very fine granular structure; nonsticky, nonplastic, hard to wet; half decomposed to undecomposed ohia lehua leaves, roots, and twigs, some charcoal; very strongly acid (pH 4.95 in 0.01 M $CaCl_2$).

Site 6 — Sample No. 6 was collected five hundred feet from site 5.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Pahoehoe lava.

Vegetation:
Ohia lehua (*Metrosideros polymorpha*)
Tree fern (*Cibotium glaucum*)
Moss
Lichens
Club moss (*Lycopodium cernuum*)
Ohelo (*Vaccinium reticulatum*)
Puakeawe (*Styphelia tameiameiae*)
Kukainene (*Coprosma ernodeoides*)
Sedge (*Machaerina mariscoides*)

Elevation: 1,303 m.

Depth

0-5 cm — Dark reddish brown (5YR 2/2) and dark yellowish brown (10YR 3/4) dry, very dark brown (10YR 2/2) wet, pressed, and rubbed, dark brown (10YR 4/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly roots); weak to structureless, very fine to coarse granular structure; loose, nonsticky, nonplastic, hard to wet; Metrosideros roots, leaves, twigs, extremely acid (pH 4.48 in 0.01 M $CaCl_2$).

Site 7 — Sample No. 7.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Pahoehoe lava.

Vegetation: Similar to those at site of Sample No. 6.

Elevation: 1,212 m.

Depth 0-1 cm	Root mass.
1-7 cm	Dark brown (7.5YR 3/2) dry, black (10YR 2/1) wet, pressed and rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 90 per cent fiber (mostly roots); weak to structureless, fine to medium granular structure; loose, nonsticky, nonplastic, hard to wet; roots and leaves mixed with small rocks and some charcoal; very strongly acid (pH 4.68 in 0.01 M $CaCl_2$).

Site 8	Two samples were collected.
Location:	Bishop Estate Land, Kona, Island of Hawaii.
Parent rock:	Pahoehoe lava.
Vegetation:	Ohia lehua (*Metrosideros polymorpha*) Tree fern (*Cibotium glaucum*) Lobelia (*Clermontia parsiflora*) Alani (*Pelea clusiaefolia*) Ieie (*Freycinetia arborea*) Carpet grass (*Axonopus affinis*)
Elevation:	1,121 m.

Sample 8-1

Depth 0-1 cm	Root mass and undecomposed leaves.
1-10 cm	Black (10YR 2/1) and very dark brown (10YR 2/2), very dark brown (10YR 2/2) pressed and rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly medium to fine to very fine roots); weak to

structureless coarse to very fine granular structure; firm when dry, nonsticky, nonplastic, hard to wet; fine roots mixed with decomposed material, some charcoal (2mm in diameter or more); extremely acid (pH 4.18 in 0.01 M $CaCl_2$).

Sample 8-2

Depth
0-10 cm — Very dark grayish brown (10YR 3/2) and very dark brown (10YR 2/2) dry, black (10YR 2/1) wet, pressed and rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 90 per cent fiber (mostly very fine to fine roots); weak to structureless fine to very fine granular structure; loose, nonsticky, nonplastic, hard to wet; roots of ohia lehua and fern mixed with decomposed material, some charcoal; extremely acid (pH 4.12 in 0.01 M $CaCl_2$).

Site 9P — Two samples were collected.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Pahoehoe lava.

Vegetation:
Ohia lehua (_Metrosideros polymorpha_)
Tree fern (_Cibotium glaucum_)
Amaumau fern (_Sadleria cyatheoides_)
False staghorn fern (_Dicranopteris emarginata_)
Thimble berry (_Rubus rosaefolius_)
Hilo grass (_Plaspalum conjugatum_)
Carpet grass (_Axonopus affinis_)
Yorkshire fog (_Holcus lanatus_)
Puahanui (_Broussaisia arguta_)
Ieie vine (_Freycinetia arbosa_)
Mamaki (_Pipturus albidus_)

Elevation: 970 m.

Sample 9P-1

Depth
0-12 cm

Very dark brown (10YR 2/2) moist, black (10YR 2/1) wet, very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (roots); loose, slightly sticky, slightly plastic; weak medium to fine crumb structure; material mixed with small rocks 1 to 10 cm in diameter, half decomposed leaves and roots of ohia lehua and fern, some charcoal; very strongly acid (pH 4.82 in 0.01 M $CaCl_2$).

Sample 9P-2

Depth
0-12 cm

Very dark brown (10YR 2/2) moist, black (10YR 2/1) wet, very dark brown (10YR 2/2) pressed, black (10YR 2/1 rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (roots); loose, slightly sticky, slightly plastic; weak to structureless, medium to fine crumb structure; organic material mixed with fine roots, tree fern twigs, small rocks and some charcoal; extremely acid (pH 4.26 in 0.01 M $CaCl_2$).

Site 9A — Approximately 500 feet below site 9P. Two samples were collected.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Same as at site of Sample 9P.

Elevation: 970 m.

Sample 9A-1

Depth
0-12 cm — Very dark brown (10YR 2/2) moist, black (10YR 2/1) wet, very dark brown (10YR 2/1) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 25 per cent fiber (mostly roots); weak structure, coarse to fine granular structure; loose, nonsticky, non-plastic; composed of fine roots, leaves and stump; very strongly acid (pH 4.90 in 0.01 M $CaCl_2$).

Sample 9A-2

Depth
0-12 cm — Very dark brown (10YR 2/2), black (10YR 2/1) wet, very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); loose, nonsticky, nonplastic; weak structure, coarse to fine granular to subangular blocky structure; material mixed with fine roots, leaves, and stumps; strongly acid (pH 5.52 in 0.01

M $CaCl_2$).

Site 10 — Two samples were collected.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (Metrosideros polymorpha)
Tree fern (Cibotium glaucum)
Amaumau fern (Sadleria cyatheoides)
Hilo grass (Paspalum conjugatum)
Carpet grass (Axonopus affinis)
Ieie vine (Freycinetia arbosa)
Swordfern (Nephrolepis exaltata)
Thimble berry (Rubus rosaefolius)
Paint brush (Orthocarpus purpurascens)

Elevation: 727 m.

Sample 10-1

Depth
0-10 cm — Black (10YR 2/1), very dark brown (10YR 2/2) pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber; loose, slightly sticky, slightly plastic; weak to structureless, medium to very fine crumb structure, formed strong coarse to fine subangular blocky structure when dry; material mixed with small rocks; very strongly acid (pH 4.88 in 0.01 M $CaCl_2$).

Sample 10-a — Similar to Sample 10-1.

Site 11 — Two samples were collected.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock:	Pahoehoe lava.
Vegetation:	Ohia lehua (*Metrosideros polymorpha*) Tree fern (*Cibotium glaucum*) Ieie vine (*Freycinetia arborea*) Thimble berry (*Rubus rosaefolius*) Naio or false sandal wood (*Myoporum sandwicense*) Kikuyu grass (*Pennisetum clandestinum*) Hilo grass (*Paspalum conjugatum*) Carpet grass (*Axonopus affinis*) Para grass (*Panicum purpurascens*) Guava (*Psidium guajava*)
Elevation:	591 m.

Sample 11-1

Depth
0-10 cm

Black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, light yellowish brown (10YR 6/4) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 50 per cent fiber (roots); loose, slightly sticky, slightly plastic; weak to structureless, coarse to fine crumb structure; material mixed with big and small rocks, roots and leaves, some charcoal; strongly acid (pH 5.00 in 0.01 M $CaCl_2$).

Sample 11-2

Depth
0-10 cm

Black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless, corase to fine crumb structure; material mixed with rocks, roots, leaves, and some charcoal; strongly acid (pH 5.03 in 0.01 M $CaCl_2$).

Site 12 Two samples were collected.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Aa lava.

Vegetation:
Ohia lehua (*Metrosideros polymorpha*)
Tree fern (*Cibotium glaucum*)
Ieie vine (*Freycinetia arborea*)
Thimble berry (*Rubus rosaefolius*)
Naio or false sandal wood (*Myoporum sandwicense*)
Kikuyu grass (*Pennisetum clandestinum*)
Hilo grass (*Plaspalum conjugatum*)
Para grass (*Planicum purpurascens*)
Guava (*Psidium guajava*)
Joee

Elevation: 515 m.

Sample 12-1

Depth
0-10 cm

Black (10YR 2/1), black (10YR 2/1) pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic, coarse to medium, weak to structureless crumb structure; material mixed with roots, twigs, and rocks; strongly acid (pH 5.42 in 0.01 M $CaCl_2$).

Sample 12-2

Depth
0-10 cm

Black (10YR 2/1), black (10YR 2/1) pressed and rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless, coarse to fine crumb structure; material mixed with fern roots, rocks; strongly acid (pH 5.30 in 0.01 M $CaCl_2$).

Site 13 Two samples were taken.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Pahoehoe lava.

Vegetation:
Ohia lehua (Metrosideros polymorpha)
Lantana (Lantana camara)
Guava (Psidium guajava)
Red top (Agrostis stolonifera)
Para grass (Panicum purpurascens)
Kikuyu grass (Pennisetum clandestinum)
Paint brush (Orthocarpus purpurascens)
Morning glory (Convolvulus arvensis)
Kaimi clover

Elevation: 333 m.

Sample 13-1

Depth
0-5 cm Black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3); less than 25 per cent fiber (mostly roots); loose, slightly sticky, slightly plastic; weak to structureless, fine to very fine crumb structure; material mixed with twig roots, fern stump; medium acid (pH 5.74 in 0.01 M $CaCl_2$).

Sample 13-2

Depth
0-5 cm Black (10YR 2/1) very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3); less

than 25 per cent fiber (mostly roots); loose, slightly sticky, slightly plastic; weak to structureless, corase to very fine granular structure; material mixed with recent roots and leaves; medium acid (pH 5.74 in 0.01 M $CaCl_2$).

Site 14 — Two samples were collected.

Location: Bishop Estate Land, Kona, Island of Hawaii.

Parent rock: Aa lava.

Vegetation:
Ohia lehua (*Metrosideros polymorpha*)
Lantana (*Lantana camara*)
Koa (*Acacia koa*)
Guava (*Psidium guajava*)
Morning glory (*Convolvulus arvensis*)
Molasses grass (*Melinis munitiflora*)
Christmas berry (*Schinus terebinthifolius*)

Elevation: 303 m.

Sample 14-1

Depth
0-5 cm — Very dark brown (10YR 2/2) to black (10YR 2/1), black (10YR 2/1) pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 50 per cent fiber (mostly roots); loose, nonsticky, nonplastic; weak to structureless, fine to very fine granular structure; material mixed with fine to very fine roots, leaves, stumps, and small rocks, some charcoal; medium acid (pH 5.76 in 0.01 M $CaCl_2$).

Sample 14-2

Depth
0-5 cm

Black (10YR 2/1) very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless fine to very fine crumb structure; material mixed with medium to fine roots; medium acid (pH 5.91 in 0.01 M $CaCl_2$).

The Kainaliu Sequence

The trial is below the Kealakekua sequence (see map, Fig. 14). There are only three sites that samples could be collected due to the trail is passing through mineral soils.

Site 16 — Two samples were collected.

Location: Kona, Island of Hawaii.

Parent rock: Aa lava.

Vegetation:
Ohia lehua (Metrosideros polymorpha)
Tree fern (Cibotium glaucum)
Koa (Acacia koa)
Naio or false sandal wood (Myoporum sandwicense)
Mamane (Sophora chrysophylla)
Puu lehua (Microlaena stipoides)
Compositae

Elevation: 1,242 m.

Sample 16-1

Depth
0-10 cm

Very dark brown (10YR 2/2) to black (10YR 2/1), black (10YR 2/1) pressed, rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 25 per cent fiber (mostly roots); loose, nonsticky, nonplastic; weak to structureless, fine to very fine granular structure; material mixed with rocks 1 to 10 cm in diameter, roots, leaves, and some charcoal; very strongly acid (pH 4.72 in 0.01 M $CaCl_2$).

Sample 16-2

Depth
0-10 cm — Very dark grayish brown (10YR 3/2) to very dark brown (10YR 2/2), black (10YR 2/1) wet, pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly roots); loose, nonsticky, nonplastic; coarse to fine granular structure; roots, small rocks, and some charcoal mixed with decomposed material; strongly acid (pH 5.10 in 0.01 M $CaCl_2$).

Site 15 — Two samples were collected.

Location: Kona, Island of Hawaii.

Parent rock: Aa lava.

Vegetation:
Ohia lehua (*Metrosideros polymorpha*)
Tree fern (*Cibotium glaucum*)
Sword fern (*Nephrolepis exaltata*)
False staghorn fern (*Dicranopteris emarginata*)
Amaumau fern (*Sadleria cyatheoides*)
Yellow foxtail (*Setaria geniculata*)
Thimble berry (*Rubus rosaefolius*)
Carpet grass (*Axonopus affinis*)
Kikuyu (*Pennisetum clandestinum*)
Fern (*Asplenium contiguum*)

	Moss Lichens
Elevation:	977 m.

Sample 15-1

Depth 0-10 cm	Very dark brown (10YR 2/2) dry, black (10YR 2/1) wet, pressed, rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20^{o}C (68^{o}F); less than 25 per cent fiber (mostly roots); loose, nonsticky, nonplastic; coarse to medium granular structure; material mixed with roots, leaves, stump, small rocks and some charcoal; very strongly acid (pH 4.93 in 0.01 M $CaCl_2$).

Sample 15-2

Depth 0-10 cm	Very dark brown (10YR 2/2), black (10YR 2/1) wet, pressed, rubbed, dark brown (7.5YR 3/2) in saturated sodium pyrophosphate solution at 20^{o}C (68^{o}F); more than 50 per cent fiber (mostly roots); loose nonsticky, nonplastic; medium to fine granular structure; material mixed with fine to very fine roots, some fern stump and some rocks; extremely acid (pH 4.37 in 0.01 M $CaCl_2$).

Site 17	Two samples were collected.
Location:	Kona, Island of Hawaii.
Parent rock:	Aa lava.

Vegetation: Ohia lehua (*Metrosideros polymorpha*)
Tree fern (*Cibotium glaucum*)
Guava (*Psidium guajava*)
Black-fruited Coprosma (*Coprosma ernodeoides*)
Fern (*Asplenium contiguum*)

Elevation: 909 m.

Sample 17-1

Depth
0-10 cm Very dark brown (10YR 2/2) to black (10YR 2/1), very dark brown (10YR 2/2) pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly roots); loose, nonsticky, nonplastic; coarse to very fine granular structure; material mixed with fine to very fine roots, partly decomposed leaves, and some small rocks; medium acid (pH 5.52 in 0.01 M $CaCl_2$).

Sample 17-2 Similar to that of Sample 17-1.

Stainback Highway Sequence

Sample collection was made on December 30, 1969. The samples along this sequence were collected by H. Ikawa, R. Oldeman, and N. Yaibuathes. Plant samples were identified by K. Kartawinata.

Site 18 Two samples were collected.

Location: Stainback Highway, Hilo, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (*Metrosideros polymorpha*)
False staghorn fern (*Dicranopteris emarginata*)
Amaumau fern (*Sadleria cyantheoides*)
Puakeawe (*Styphelia tameiameiae*)

	Manono (*Gouldia terminalis*) Ohelo (*Vaccinium reticulatum*) Tree fern (*Cibotium glaucum*) Pilo (*Coprosma orchracea*) (*Marchaerina mariscoides*)
Elevation:	1,439 m.
Sample 18-1	
Depth 0-1 cm	Undecomposed leaves and roots.
0-12 cm	Very dark brown (10YR 2/2) to black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 50 per cent fiber (mostly fiber); slightly sticky, slightly plastic; weak to structureless, fine to very fine crumb structure; material mixed with roots and some rocks; extremely acid (pH 3.85 in 0.01 M $CaCl_2$).
Sample 18-2	Similar to that of Sample 18-1.
Sample 19	Two samples were collected.
Location:	Stainback Highway, Hilo, Island of Hawaii.
Parent rock:	Aa lava.
Vegetation:	Ohia lehua (*Metrosideros polymorpha*) Tree fern (*Cibotium glaucum*) False staghorn fern (*Dicranopteris emarginata*) Palapalai fern (*Microlepia setosa*) Loulu fern (*Coniogramme pilosa*) Moss
Elevation:	1,364 m.

Sample 19-1

Depth	
0-7 cm	Fern and ohia lehua roots and leaves.
7-25 cm	Very dark brown (10YR 2/2) to black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, light yellowish brown (10YR 6/4) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless, fine to very fine crumb structure; material mixed with roots, 0.2 to 1 cm olivine basalt were found; very strongly acid (pH 4.79 in 0.01 M $CaCl_2$).

Sample 19-2

Depth	
0-5 cm	Root mass.
5-20 cm	Very dark brown (10YR 2/2) to black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 50 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless, medium to fine crumb structure; plenty of rocks 5 to 10 cm in diameter, disintegrating and relatively fresh olivine basalt, fern stump, dominant part of fiber are roots; strongly acid (pH 5.16 in 0.01 M $CaCl_2$).

Site 20 Two samples were collected.

Location: Stainback Highway, Hilo, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (*Metrosideros polymorpha*)
Tree fern (*Cibotium glaucum*)
False staghorn fern (*Dicranopteris emarginata*)
Amaumau fern (*Sadleria cyatheoides*)
Kilau or blacken fern (*Pteridium aquilinum*)
Loulu fern (*Coniogramme pilosa*)
Mamaki (*Piturus albidus*)
Thimble berry (*Rubus rosaefolius*)
Manono (*Gouldia terminalis*)
Moss

Elevation: 1,212 m.

Sample 20-1

Depth

0-2 cm Roots and leaves.

2-27 cm Very dark brown (10YR 2/2) wet, pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 50 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless, medium to fine crumb structure; some volcanic glass being exposed when dry, both weathering and unweathering olivine basalt are found, dominant fern roots; very strongly acid (pH 4.67 in 0.01 M $CaCl_2$).

Sample 20-2 The description is similar to that of Sample 20-1, except this one shows strongly acid reaction (pH 5.08 in 0.01 M $CaCl_2$).

Site 21 Two samples were collected.

Location: Stainback Highway, Hilo, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (Metrosideros polymorpha)
Tree fern (Cibotium glaucum)
Amaumau fern (Sadleria cyatheoides)
Olapa (Cheirodendron trigynum)
Coprosma (Coprosma rhynchocarpa)
Puahanui (Broussaisia arguta)

Elevation: 1,015 m.

Sample 21-1 Depth ranging from 7.5-37.5 cm, average 27.5 cm.

Depth

0-2 cm Decomposing leaves, twig and root mass.

2-27 cm Dark brown (7.5YR 3/2), very dark brown (10YR 2/2), black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to structureless, coarse to fine crumb structure; plenty saprolite mixed with organic soil material; very strongly acid (pH 4.79 in 0.01 M $CaCl_2$).

Sample 21-2 Similar to that of Sample 21-1.

Site 22 Two samples were collected.

Location: Stainback Highway, Hilo, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (Metrosideros polymorpha)
Tree fern (Cibotium glaucum)
False staghorn fern (Dicranopteris emarginata)
Puahanui (Broussaisia arguta)
Ieie vine (Freycinetia arborea)
Moss

Elevation: 818 m.

Sample 22-1 Depth ranges from 7.5-40 cm, average 30 cm.

Depth
0-2 cm Decomposing leaves and root mass.

2-27 cm Black (10YR 2/1) to very dark brown (10YR 2/2), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; weak to medium granular structure; ohia lehua and fern roots; very strongly acid (pH 4.50 in 0.01 M $CaCl_2$).

Sample 22-2 Depth is the same as Sample 22-1.

Depth
0-2 cm Root mass.

2-27 cm Black (10YR 2/1) to very dark brown (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; massive; fern and ohia lehua roots mixed with saprolite; very strongly acid (pH 4.90 in 0.01 M $CaCl_2$).

Site 23	Two samples were collected.
Location:	Stainback Highway, Hilo, Island of Hawaii.
Parent rock:	Aa lava.
Vegetation:	Ohia lehua (<u>Metrosideros polymorpha</u>) False staghorn fern (<u>Dicranopteris emarginata</u>) Sword fern (<u>Nephrolepis exaltata</u>) Moss
Elevation:	606 m.

Sample 23-1 Depth 13-25 cm, average 22.5 cm.

Depth	
0-2 cm	Root mass.
2-22 cm	Very dark brown (10YR 2/2) pressed, rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; massive; roots and decomposing leaves mixed with olivine basalt and some volcanic glass; very strongly acid (pH 4.81 in 0.01 M $CaCl_2$).

Sample 23-2

Depth	
0-2 cm	Root mass.
2-22 cm	Black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; massive; roots and decomposing leaves mixed with olivine basalt and

volcanic glass; very strongly acid (pH 4.71 in 0.01 M $CaCl_2$).

Site 24 — Two samples were collected.

Location: Stainback Highway, Hilo, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (Metrosideros polymorpha)
Tree fern (Cibotium glaucum)
Moss

Elevation: 303 m.

Sample 24-1 — Depth 7.5-30 cm, average 20 cm.

Depth

0-2 cm — Root mass.

2-20 cm — Black (10YR 2/1) to very dark brown (10YR 2/2), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; massive; decomposing leaves and roots; extremely acid (pH 4.46 in 0.01 M $CaCl_2$).

Sample 24-2

Depth

0-2 cm — Root mass.

2-20 cm — Black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1), pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); less than 25 per cent fiber (mostly roots); slightly sticky, slightly plastic; massive; ohia lehua roots and leaves mixed with small rocks; very strongly acid (pH 4.83 in 0.01 M $CaCl_2$).

Samples 1, 2, and 4 were collected within the Experiment Station.

Location: Malama Ki Branch Station, Hawaii Agricultural Experimental Station, University of Hawaii, Stainback Highway, Hilo, Island of Hawaii.

Parent rock: Aa lava.

Vegetation: Ohia lehua (Metrosideros polymorpha)
Tree fern (Cibotium glaucum)
Manono (Gouldia terminalis)
Sword fern (Nephrolepis exaltata)
Palapalaa (Sphenomeris chusana)
Strawberry guava (Psidium catleianum)
Wild orchid
Moss

Elevation: 151 m.

Site 1 Sample 1 grab sample. One hundred feet west from the south corner of the Branch Station. Ohia was the dominant species.

Depth
0-5 cm Black (10YR 2/1) very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20^{o}C (68^{o}F); about 90 per cent fiber (mostly roots); weak to structureless, medium to very fine crumb structure; slightly sticky, slightly plastic; many fine roots less than 5 mm, highly decomposed material appears to

be from leaves of fern and ohia lehua; strong biological activities; very strongly acid (pH 4.52 in 0.01 M $CaCl_2$).

Site 2 — Sample 2. Five hundred feet north of Sample 1, fern was dominant. Grab sample from pockets in rocks.

Depth 0-7 cm — Dark reddish brown (5YR 2/2), dark reddish brown (5YR 3/2) pressed, dark reddish brown (5YR 2/2) rubbed, dark brown (7.5YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly medium to fine roots); weak to structureless, coarse to medium crumb structure; loose, slightly sticky, slightly plastic; ohia lehua roots, tree fern trunk, twigs, and roots; extremely acid (pH 4.06 in 0.01 M $CaCl_2$).

Site 4 — Sample 4. Irregular and very shallow sample site.

Depth 0-5 cm — Very dark brown (10YR 2/2), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, dark brown (10YR 4/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber; weak to structureless, fine to very fine crumb structure; loose, slightly sticky, slightly plastic; ohia lehua leaves and roots, tree fern leaves and roots, mosses; strongly acid (pH 5.12 in 0.01 M $CaCl_2$).

Hawaiian Troposaprists
(The Alakai Series)

Sample collection was made on March 30, 1970. The samples were collected by H. Ikawa, C. L. Schroth, R. Oldeman, and N. Yaibuathes.

Location: On top of Mt. Kaala, Island of Oahu.

Parent rock: Basic igneous rock.

Vegetation: Ohia lehua (*Metrosideros polymorpha*)
Prickly Florida Blackberry (*Rubus penetrans*)
Kawaii (*Ilex anomala*)
Amaumau fern (*Sadleria cyantheoides*)
Puahanui (*Broussasia arguta*)
Ohelo (*Styphelia tameiameiae*)
Olapa (*Cheirodendron trigynum*)
(*Machaerina mariscoides*)

Elevation: 1,220 m.

Note: Two profiles were collected. Profile I is on slope. Profile II is in depression.

Profile I Samples No. 25, 26, 27, and 28.

Horizon	Depth (cm)	Description
1 (Sample 25)	0-5	Root mass; black (10YR 2/1) to very dark brown (10YR 2/2), black (10YR 2/1) pressed and rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 90 per cent fiber (mostly roots); slightly sticky, slightly plastic; very weak to structureless, fine to very fine crumb structure; extremely acid (pH 3.02 in 0.01 M $CaCl_2$).

Horizon	Depth (cm)	Description
2 (Sample 26)	5-17	Black (10YR 2/1) to very dark brown (10YR 2/2), very dark brown (10YR 2/1) pressed, black (10YR 2/1) rubbed, yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber (mostly roots); slightly sticky, slightly plastic; very weak to structureless crumb structure; roots and decomposing fern stump; extremely acid (pH 3.11 in 0.01 M $CaCl_2$).
3 (Sample 27	17-32	Same as the above except more fine roots were found
4 Sample 28)	32-40	Black (10YR 2/1) to very dark brown (10YR 2/2) and dark yellowish brown (10YR 4/2), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, light yellowish brown (10YR 6/4) in saturated sodium pyrophosphate solution at 20°C (68°F); about 50 per cent fiber; very sticky, very plastic; massive; the most decomposing materials; extremely acid (pH 2.88 in 0.01 M $CaCl_2$).

Note: Digging was stopped at 16" because of water table.

Profile II Samples No. 29, 30, 31 and 32.

Horizon	Depth (cm)	Description
1 (Sample 29)	0-12	Root mass; very dark brown (10YR 2/2) to black (10YR 2/1), very dark brown (10YR 2/2), black (10YR 2/1) rubbed, light yellowish brown (10YR 6/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 75 per cent fiber; slightly sticky, slightly plastic; very weak to structureless, medium to fine crumb structure; mostly roots, decomposing leaves and stumps; extremely acid (pH 2.70 in 0.01 M $CaCl_2$).
2 (Sample 30)	12-27	Black (10YR 2/1), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, light yellowish brown (10YR 6/4) in saturated sodium pyrophosphate solution at 20°C (68°F); more than 50 per cent fiber; slightly sticky, slightly plastic; very weak to structureless, medium to fine crumb structure; medium to very fine roots; extremely acid (pH 2.76 in 0.01 M $CaCl_2$).
3 (Sample 31)	27-80	Black (10YR 2/1) to very dark brown (10YR 2/2), very dark brown (10YR 2/2) pressed, black (10YR 2/1) rubbed, pale brown (10YR 6/3) in saturated sodium pyrophosphate solution at 20°C (68°F); about 50 per cent fiber; slightly sticky, slightly

Horizon	Depth (cm)	Description
		plastic; massive; decomposing roots and leaves mixed with well-decomposed material; extremely acid (pH 3.08 in 0.01 M $CaCl_2$).
4 (Sample 32)	80-87	Mixture of white (10YR 8/1), dark grayish brown (10YR 4/2), very dark brown (10YR 2/2) and black (10YR 2/1), yellowish brown (10YR 5/4) in saturated sodium pyrophosphate solution at 20°C (68°F); very sticky, very plastic; massive; organic soil material mixed with mineral soil; extremely acid (pH 3.59 in 0.01 M $CaCl_2$).